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AFML-TR-78-179

COLLECTED ENGINEERING DATA SHEETS
(AIR FORCE DATA SHEET PROGRAM)

BATTELLE
COLUMBUS LABORATORIES
505 King Avenue
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FINAL REPORT April 1965 to September 1978

Approved for public release; distribution unlimited.

AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

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Fatigue Properties
Creep Properties
Chemical Composition
Aluminum Alloys
Physical Properties
Titanium Alloys
High Strength Steel Alloys

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The major objectives of this program were to evaluate newly developed materials of interest to the Air Force for potential airframe structural usage, and to provide "data sheet"-type presentations of engineering data for these materials. This report presents a collection of all of the data sheets generated to date on the Air Force Data Sheet Program.

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FOREWORD

This report was prepared by Battelle's Columbus Laboratories, Columbus, Ohio, under Contract F33615-77-C-5009. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth (AFML/MXA), Technical Manager.

This final report covers work conducted from April 1965 to September 1978. This report was submitted by the author on October 5, 1978.

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INTRODUCTION

Materials for U.S. Air Force advanced weapons systems must meet new combinations of design load and damage tolerance requirements as well as tightened economic and environmental constraints. New alloys and modifications in composition, processing, or product forms of existing alloys are continually being developed to meet these increased demands. However, many potentially attractive materials are either in the final development stage or have just become commercially available and, as such, engineering data adequate for evaluation and comparison to other alloys are not available. The Air Force, in recognition of this fact, has sponsored several programs at Battelle's Columbus Laboratories to provide appropriate comparative engineering data for newly developed materials. Such data could relieve the above situation and stimulate interest in the use of these alloys for advanced structures. The materials included in these evaluation programs were carefully selected to insure that they were available or could become quickly available on request and, most importantly, that they represented potentially attractive alloy projections for weapons systems usage.

Material properties investigated were tension, compression, shear, impact, bend, fracture toughness, fatigue, creep and stress rupture, and stress corrosion at appropriate temperatures and using standardized test procedures (per ASTM) where possible. This matrix was later expanded to include density, thermal expansion, bearing, and crack propagation properties. Data sheets containing typical properties were issued after the completion of each material evaluation in order to make the data rapidly available instead of waiting until the end of the contract term. No statistical significance is attached to these properties.

The "data sheet" program was first sponsored in 1965 and has continued since that date. More than 80 materials have been evaluated over the years. Data sheets have been issued for each evaluation and the supporting data have been published in final summary reports AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, AFML-TR-72-196, Volumes I and II, AFML-TR-73-114, AFML-TR-75-97, and AFML-TR-77-198. Some of the alloys, processes, or conditions evaluated since 1965 may have changed, been discontinued, or refined in some way. Those which are known are footnoted in the "Index to Structural Materials Data Sheets" which follows. It is quite possible that others have been discontinued or are special order material.

The current year's effort has resulted in six new data sheets. These were for Custom 450 strip, Ti-15V-3Cr-3Al-3Sn sheet, A206.0-T7 castings, 2240-T6 castings, C355.0-T61 castings, and Ti-4.5Al-5Mo-1.5Cr plate.

It is believed that the data sheets provide a valuable material property reference; therefore, this technical report presents, under one cover, all of the data sheets issued on this effort since its inception in 1965, including the current six new ones. In addition, it presents the supporting data for the six new data sheets.

ORGANIZATION OF REPORT

The data sheets are presented in roughly the order of publication in a previous summary report. However, to aid in assessing and locating specific materials, an index has been prepared.

The index groups the alloys by the categories:

- steel
- aluminum
- magnesium
- titanium
- heat resistant
- beryllium and special purpose.

Within each category the materials are arranged alphabetically or numerically, as appropriate. The index as presented on the following pages lists the material, thickness, processing (if pertinent), product, an abbreviated condition, and a page number. More detailed descriptions of the material and condition appears within each data sheet.

INDEX TO STRUCTURAL MATERIAL DATA SHEETS

INDEX TO STRUCTURAL MATERIAL DATA SHEETS (Continued)

INDEX TO STRUCTURAL MATERIAL DATA SHEETS (Continued)

(a) Discontinued.

(b) Inactive alloy.

(c) Experimental heat-treat condition, has probably changed.

TD Nickel

TD Nickel is a recently developed alloy containing 2 volume percent thoria and the balance nickel ($Ni\text{-}2ThO_2$). This alloy shows promise as a structural material for use in the temperature range from 1800 to 2400 F. It has excellent thermal stability, high thermal conductivity, and a high melting point.

The material has sufficient ductility for simple cold-forming operations and can be machined in the same manner as stainless steel.

Fusion welding requires special techniques to achieve sound joints. However, this alloy can be joined quite readily by brazing, ultrasonic welding, and diffusion bonding.

The alloy is available as sheet, bar, tubing, wire, foil, and forging.

TD Nickel Sheet Data[a]

Condition: Stress-relieved[b]
Thickness: 0.060 inch

Properties	Temperature, F			
	RT	1600	1800	2000
Tension				
F_{tu} (longitudinal), ksi	63.6	21.4	17.9	14.7
F_{tu} (transverse), ksi	63.8	20.6	17.1	13.3
F_{ty} (longitudinal), ksi	46.2	21.2	17.7	14.3
F_{ty} (transverse), ksi	45.6	20.3	16.8	12.9
e_t (longitudinal), percent in 2 in.	14.5	5.0	5.0	8.0
e_t (transverse), percent in 2 in.	14.5	3.0	3.0	3.0
E_t (longitudinal), 10^6 psi	16.9	10.7	9.1	8.2
E_t (transverse), 10^6 psi	17.8	10.3	8.8	8.6
Compression				
F_{cy} (longitudinal), ksi	42.1	20.9	17.2	13.6
F_{cy} (transverse), ksi	49.4	20.3	16.1	12.8
E_c (longitudinal), ksi	16.0	9.5	9.9	7.7
E_c (transverse), ksi	18.4	9.7	9.9	7.4
Shear				
F_{su} (longitudinal), ksi	57.9	NA	NA	NA
F_{su} (transverse), ksi	58.4	NA	NA	NA

Properties	Temperature, F RT	1600	1800	2000
Bend				
(transverse)	Sharpe[e]	NA	NA	NA
Impact				
(Charpy V-notch), ft-lb[3]	30.0	NA[c]	30.0	NA
Fracture Toughness				
K_{IC}, ksi $\sqrt{\text{inch}}$	(d)	NA	NA	NA
Axial Fatigue (transverse)				
Unnotched, $K_t = 1$, $R = 0.1$				
10^3 cycles, ksi	63.0	23.0	19.0	NA
10^5 cycles, ksi	57.5	19.5	16.0	NA
10^7 cycles, ksi	45.0	15.0	11.5	NA
Notched, $K_t = 3$, $R = 0.1$				
10^3 cycles, ksi	61.0	22.5	17.0	NA
10^5 cycles, ksi	39.0	15.0	12.0	NA
10^7 cycles, ksi	22.5	10.0	8.0	NA
Creep (transverse)				
0.2% elongation, 100 hours, ksi	NA	10.0	7.2	4.6
0.2% elongation, 1000 hours, ksi	NA	8.2	5.2	3.5
Stress Rupture				
Rupture, 100 hours, ksi	NA	11.0	7.8	5.4
Rupture, 1000 hours, ksi	NA	9.0	5.8	4.4
Stress Corrosion				
80% F_{ty}, 1000 hours max	No cracks[g]	NA	NA	NA
Coefficient of Thermal Expansion				
68 to 800 F	8.7×10^6 in./in./F			
Density[1,2]	0.322 lb/in.^{3}			

Properties	Temperature, F			
	RT	1600	1800	2000
Ductile-to-Brittle Bend-Transition Temperature, F	Lower than -1000 F[(f)]			
Melting Temperature	2650 F[(3)]			

(a) Data are average values.
(b) Treatment: 1 hour at 2000 F in hydrogen. Test material from two production heats.
(c) Information either not available or not applicable.
(d) Fatigue-cracked center-notched specimens (0.060 x 3 x 12 inch) failed in a ductile manner.
(e) Sharp bending tup (105-degree angle); specimen unloaded bend angle over 100 degrees; no cracks at RT.
(f) Sharp bending tup (105-degree angle); no cracks at -100 F.
(g) Alternate immersion 3-1/2 percent NaCl.

Notes: Thermal conductivity, Btu/ft^2/in./hr/1 F at 70 F - 600[(2,3)]
500 F - 380
1100 F - 300
1500 F - 320
1700 F - 340

Electrical resistivity, microhm-cm (70 F) 7.6[(2,3)]

Specific heat, Btu/lb/F 0.106[(2,3)]

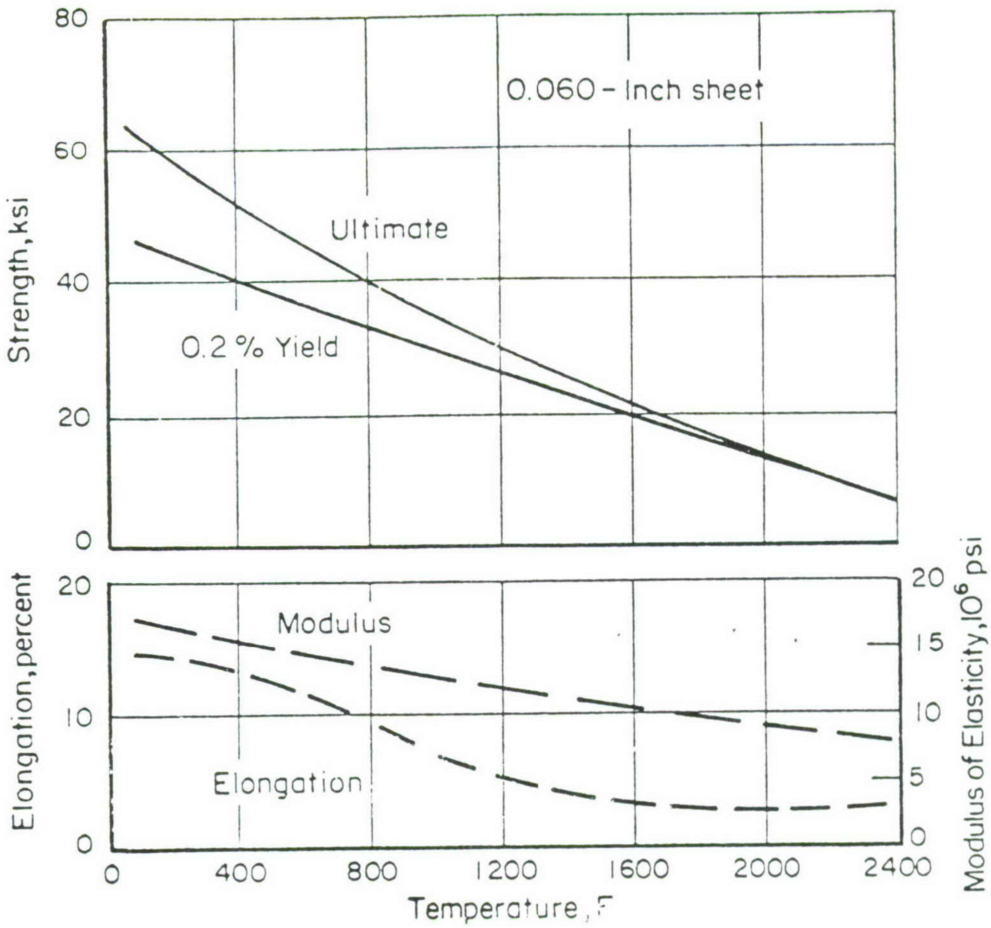


FIGURE 1 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF STRESS-RELIEVED TD NICKEL SHEET

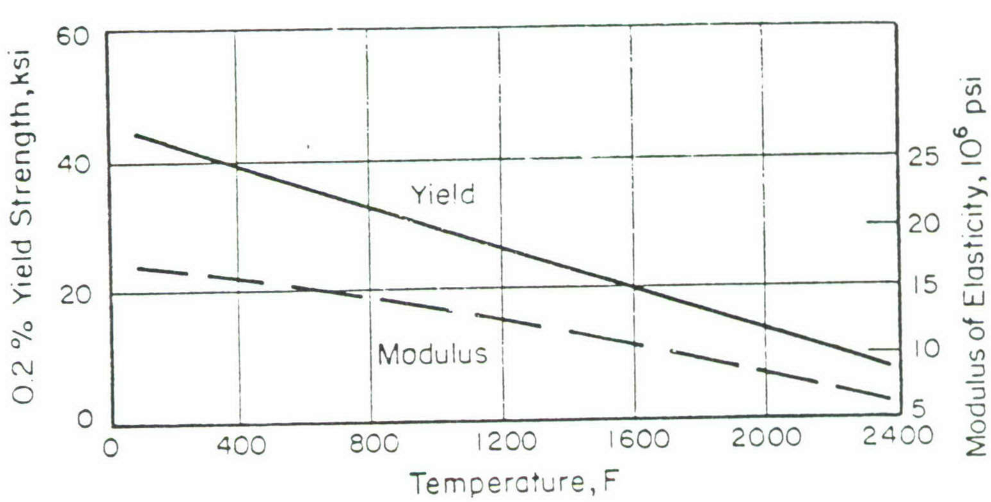


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF STRESS-RELIEVED TD NICKEL SHEET

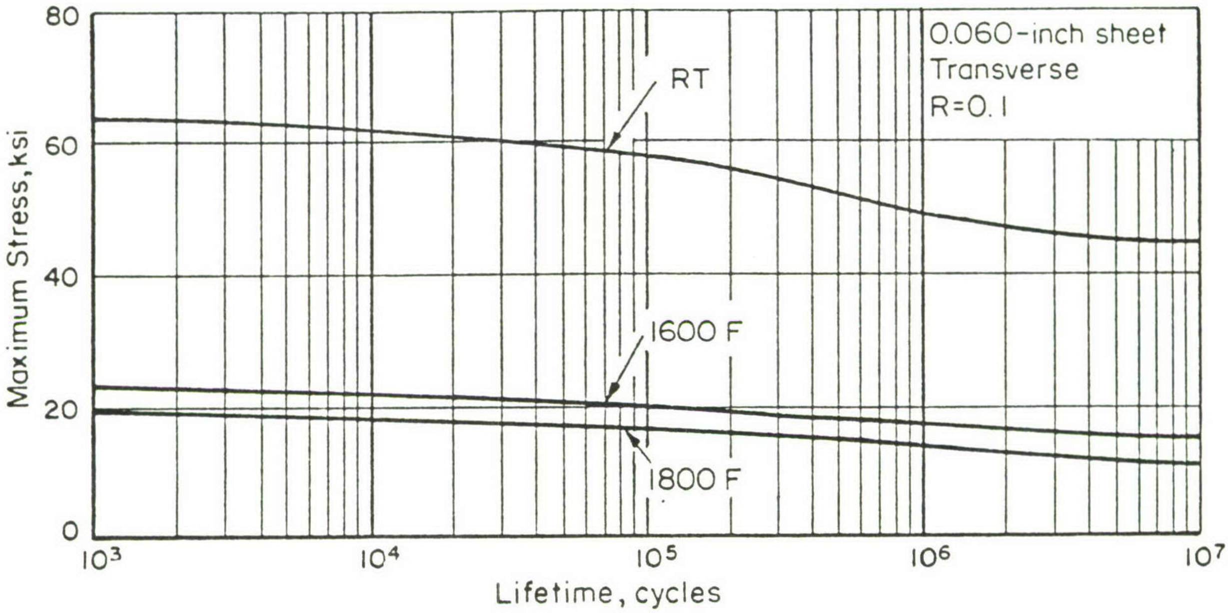


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR STRESS-RELIEVED TD NICKEL SHEET AT THREE TEMPERATURES

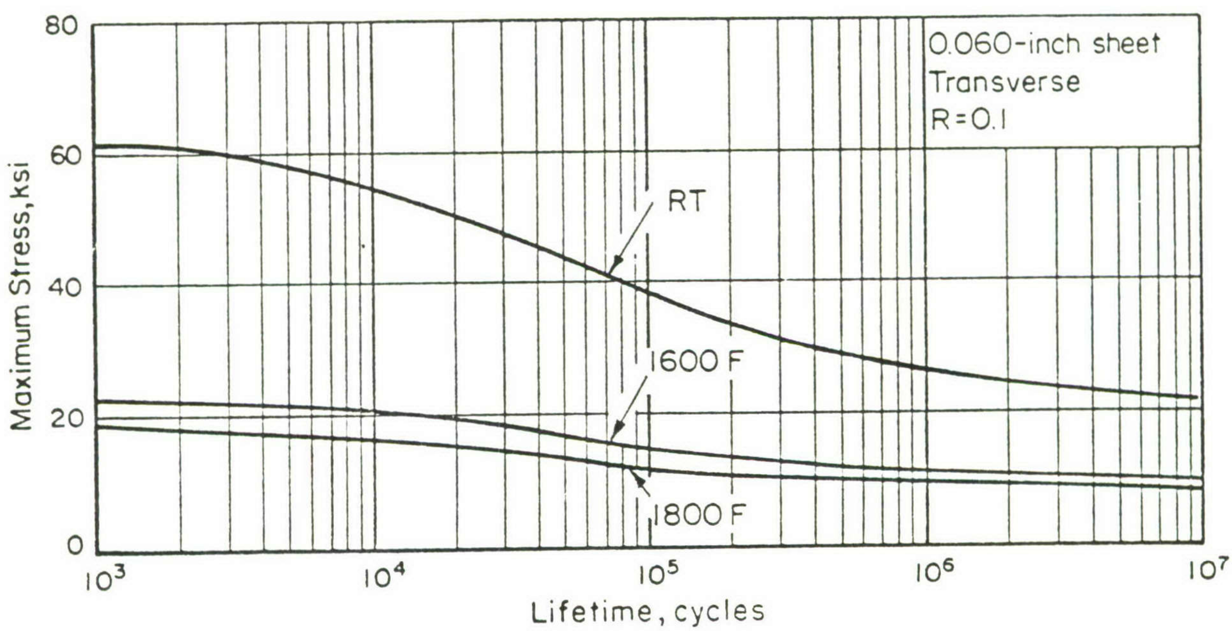


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0), STRESS RELIEVED TD NICKEL SHEET AT THREE TEMPERATURES

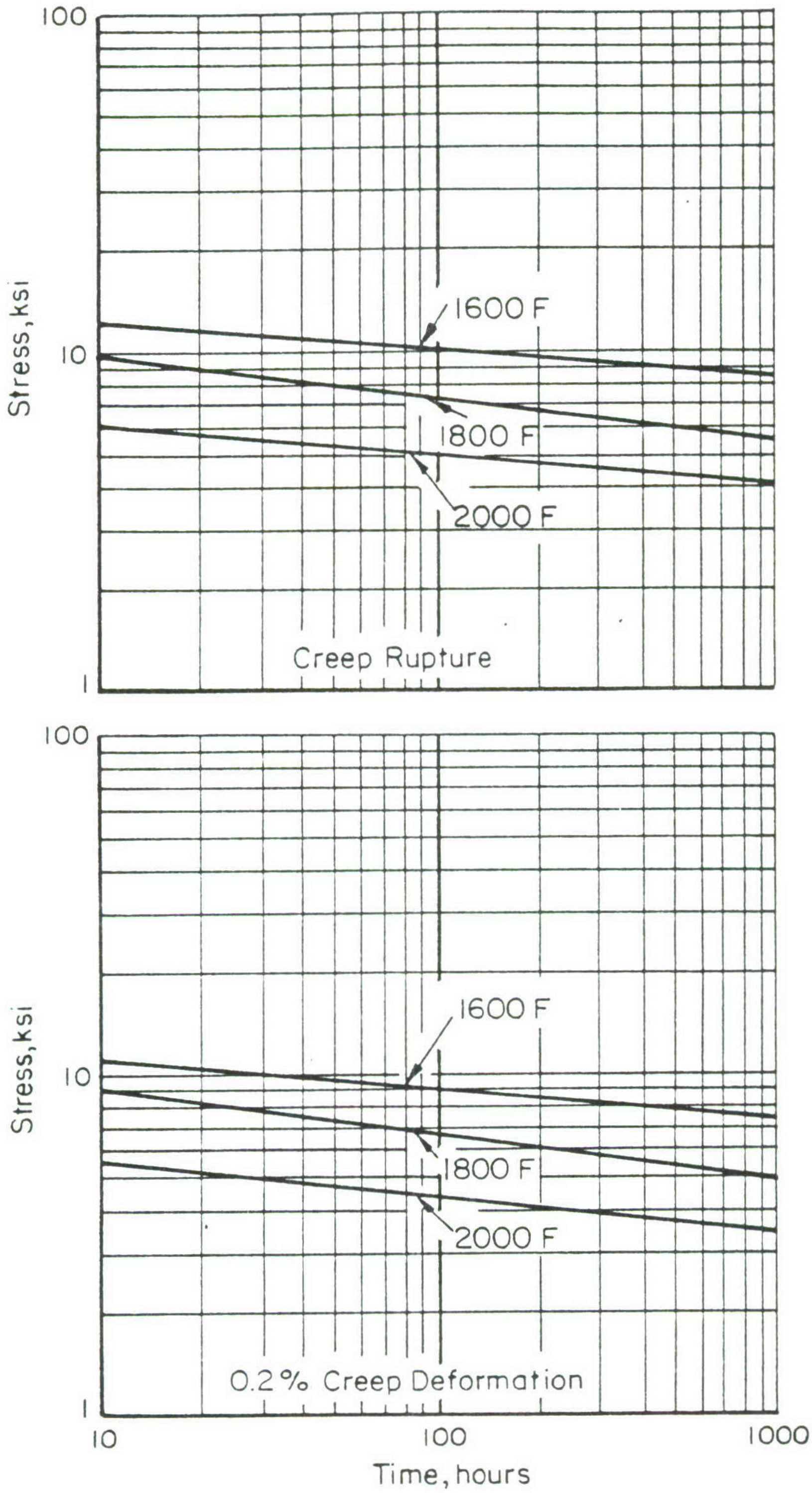


FIGURE 5. STRESS RUPTURE AND 0.2-PERCENT DEFORMATION CURVES FOR TD NICKEL SHEET (0.060 INCH) AT THREE TEMPERATURES

HP 9-4-25

The HP 9-4-25 alloy is a nickel-cobalt quenched and tempered martensitic steel possessing excellent toughness at yield strength levels up to about 200 ksi. This alloy was designed for use as plate, structural sections, and forging applications. It is especially suitable for highly stressed structures requiring good material reliability and weldability.

This steel is sensitive to thermal-mechanical treatments. In particular, both the strength and toughness can be increased by hot-cold working.

The alloy is available as sheet, plate, wire, rod, bar, and forging.

HP 9-4-25 Plate Data[a]

Condition: 1025 T temper[b]
Thickness: 0.25 inch

Properties	Temperature, F RT	500	700	900
Tension				
F_{tu} (longitudinal), ksi	197.0	182.0	165.0	138.0
F_{tu} (transverse), ksi	197.0	183.0	166.0	138.0
F_{ty} (longitudinal), ksi	184.0	161.0	146.0	123.0
F_{ty} (transverse), ksi	185.0	162.0	147.0	123.0
e_t (longitudinal), percent in 2 in.	15.0	16.0	15.0	15.7
e_t (transverse), percent in 2 in.	15.5	16.0	15.2	16.5
E_t (longitudinal), 10^6 psi	27.3	25.7	24.1	21.5
E_t (transverse), 10^6 psi	27.8	26.2	26.0	22.9
Compression				
F_{cy} (longitudinal), ksi	200.0	178.0	164.0	134.0
F_{cy} (transverse), ksi	197.0	178.0	164.0	134.0
E_c (longitudinal), 10^6 psi	30.1	28.7	27.7	25.7
E_c (transverse), 10^6 psi	28.9	27.7	26.4	24.8
Shear				
F_{su} (longitudinal), ksi	128.0	U	U	U
F_{su} (transverse), ksi	128.0	U	U	U
Impact				
Charpy V-notch, ft-lb[7]	35-50	U[c]	NA[d]	NA

Properties	Temperature, F RT	500	700	900
Fracture Toughness				
K_{IC}, ksi $\sqrt{\text{inch}}$	(e)	NA	(e)	NA
Axial Fatigue (transverse)				
Unnotched, $K_t = 1$, $R = 0.1$				
10^3 cycles, ksi(f)	202.0	210.0	208.0	U
10^5 cycles, ksi	156.0	170.0	165.0	U
10^7 cycles, ksi	140.0	158.0	150.0	U
Notched, $K_t = 3$, $R = 0.1$				
10^3 cycles, ksi	180.0	175.0	188.0	U
10^5 cycles, ksi	66.0	60.0	70.0	U
10^7 cycles, ksi	60.0	55.0	62.0	U
Creep (transverse)				
0.5% elongation, 100 hours, ksi	NA	(g)	135.0	80.0
0.5% elongation, 1000 hours, ksi	NA	(g)	130.0	64.0
Stress Rupture				
Rupture 100 hours, ksi	NA	(g)	150.0	100.0
Rupture 1000 hours, ksi	NA	(g)	138.0	68.0
Stress Corrosion				
80% F_{ty}, 1000 hours max	No cracks(h)	U	U	U
Coefficient of Thermal Expansion				
68 to 800 F(6)	6.4×10^6 in./in./F			
Density(6)	0.28 lb/in.^{3}			

(a) Data are from tests conducted at Battelle under the subject contract unless otherwise indicated. In most cases data are average values for three tests. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.
(b) Treatment: 1 hour at 1600 F AC; 1 hour at 1525 F OQ; 2 + 2 hours at 1025 F.
(c) Information unavailable.
(d) Information not applicable.

(e) Fatigue-cracked single-edge-notched specimen (2 x 8 inches at RT, 2 x 13-1/4 inches at ET) failed in ductile manner. Nominal notch strength 100 to 103 ksi.

(f) "K_t" represents Neuber-Peterson theoretical stress-concentration factor. "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$.

(g) Steel did not go to 0.5% elongation or to rupture at 500 F when stressed to tensile yield-strength level.

(h) Alternate immersion, 3-1/2% NaCl.

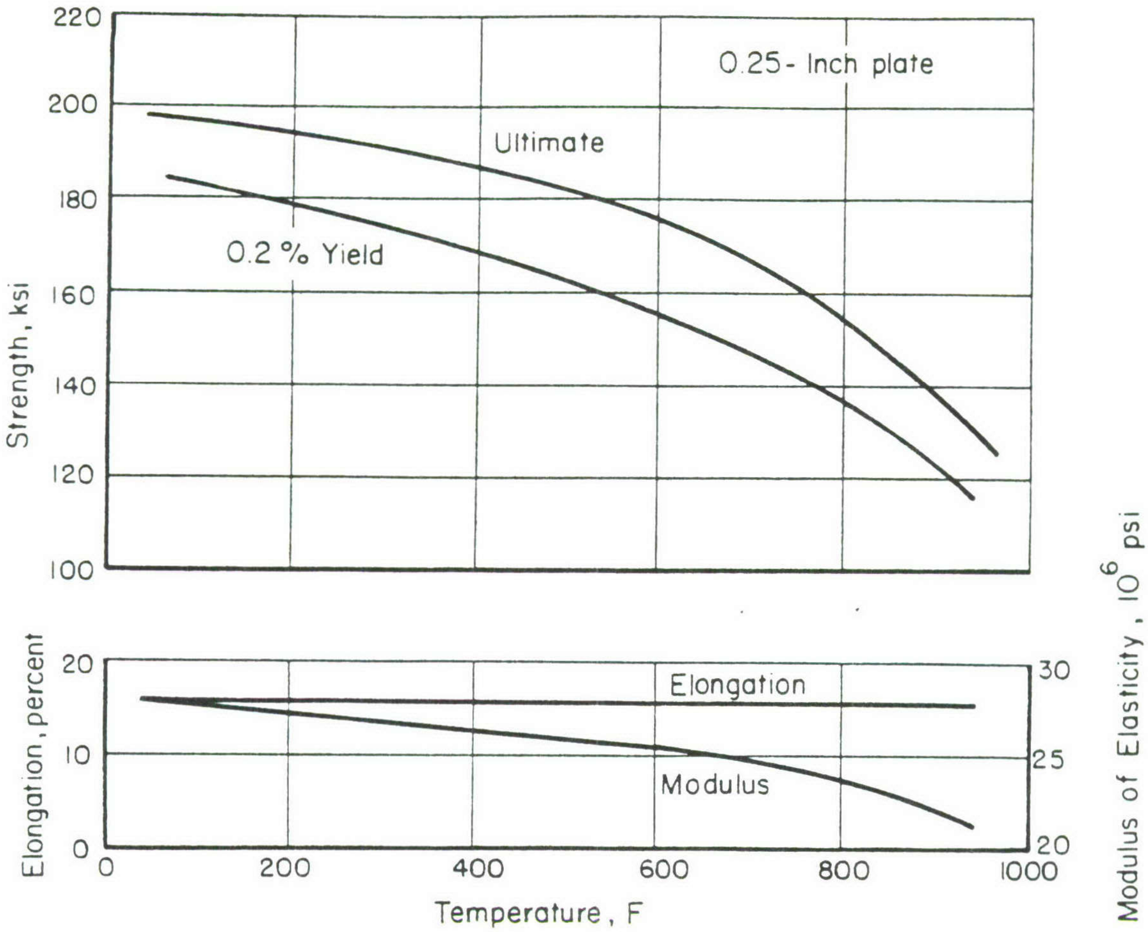


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF QUENCHED AND TEMPERED HP 9-4-25 PLATE

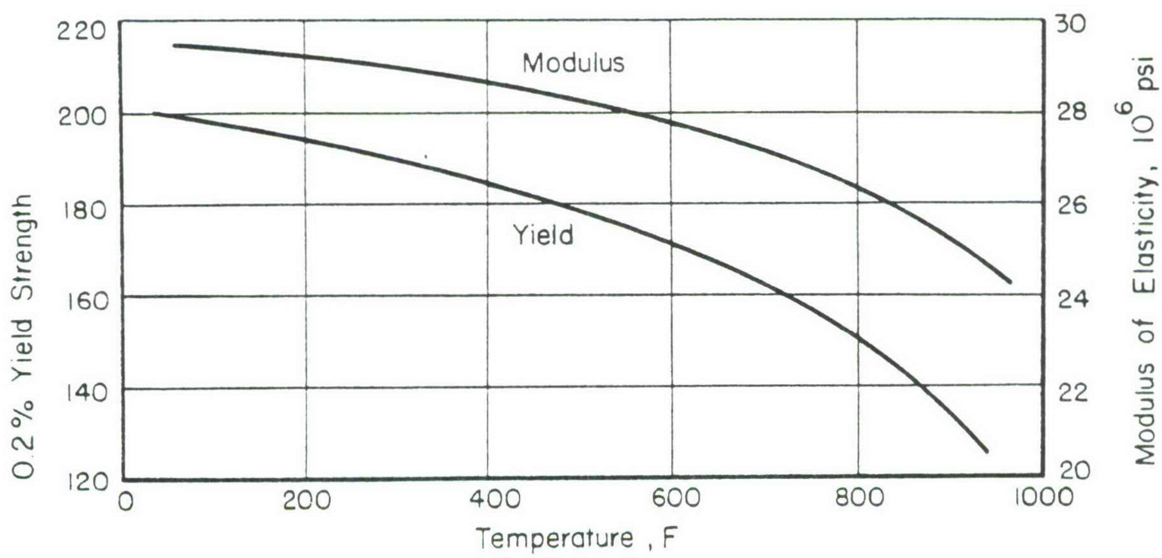


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF QUENCHED AND TEMPERED HP 9-4-25 PLATE

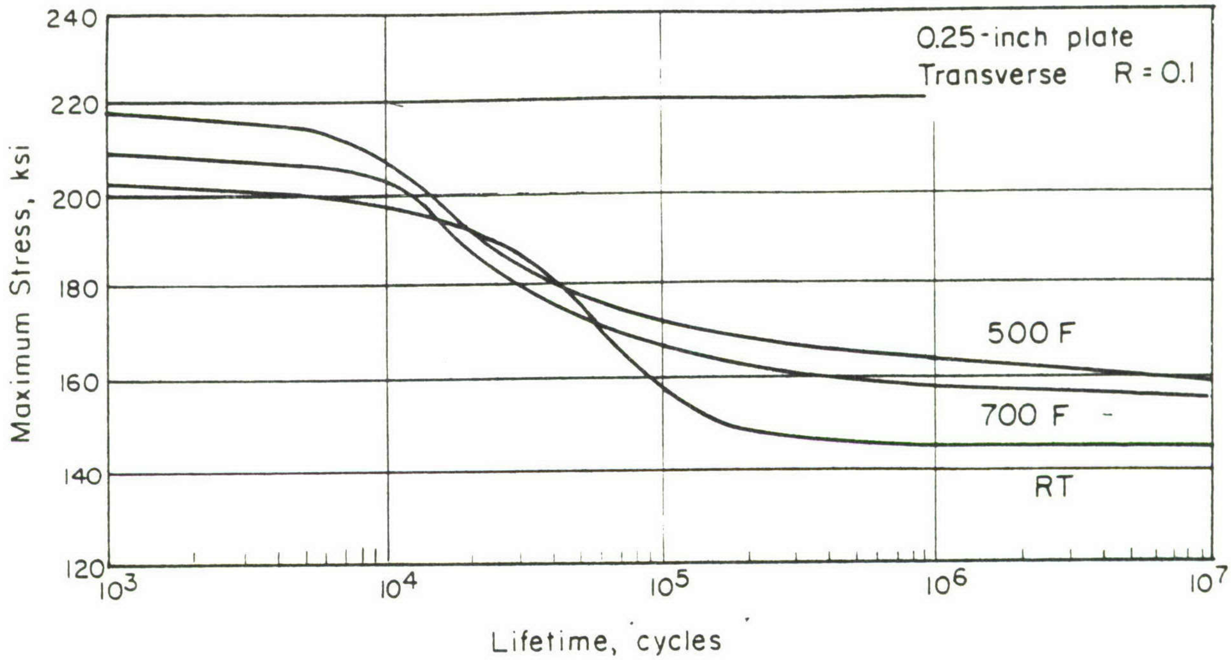


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR QUENCHED AND TEMPERED HP 9-4-25 PLATE AT THREE TEMPERATURES

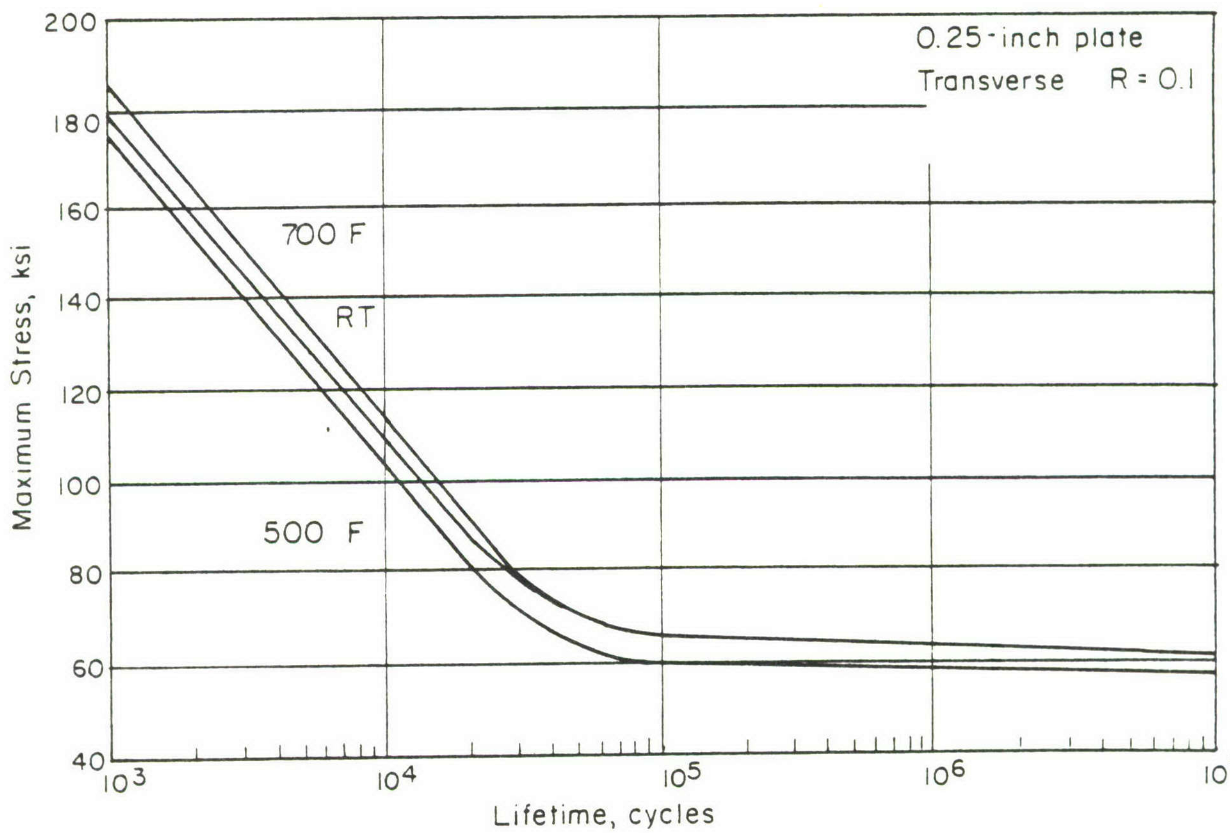


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) QUENCHED AND TEMPERED HP 9-4-25 PLATE AT THREE TEMPERATURES

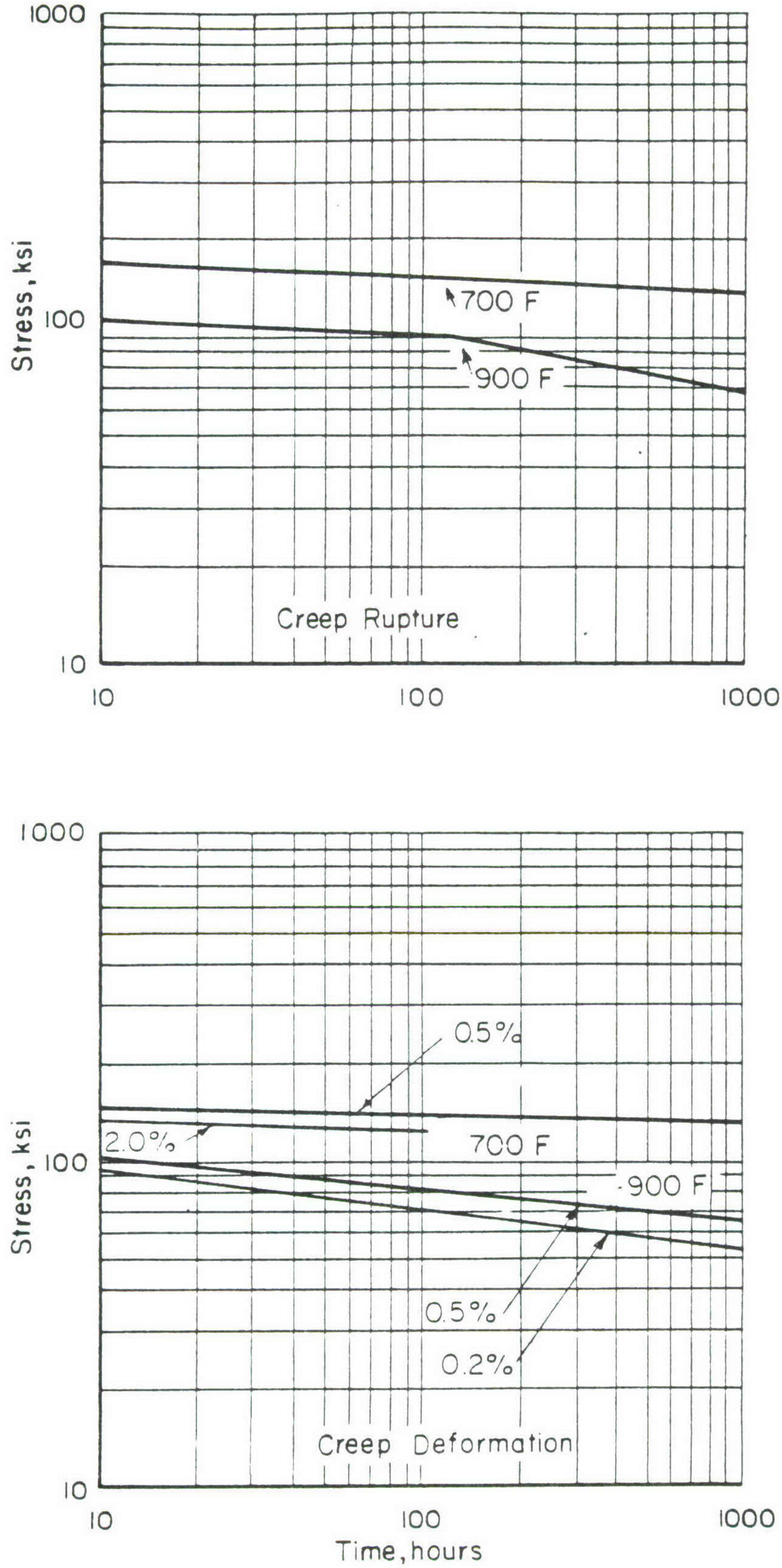


FIGURE 5. STRESS RUPTURE AND 0.5 PERCENT DEFORMATION CURVES FOR HP 9-4-25 PLATE (0.25-INCH) AT TWO TEMPERATURES

HP 9-4-45

The HP 9-4-45 alloy is a nickel-cobalt steel which possesses high strength with good toughness. A quench and temper heat treatment may be used for sheet and thin sections to produce a tempered martensitic structure. This treatment provides 250 psi yield and 290 ksi ultimate tensile-strength levels while maintaining adequate toughness. An alternative heat treatment that produces a bainitic structure increases the section size that can be hardened. The bainitic treatment at yield strengths of 230 ksi and ultimate strengths of 270 ksi increases the toughness for all product forms.

This alloy is intended to be fabricated in the annealed condition. It can be TIG welded in the annealed condition but requires post treatment to achieve high joint efficiencies.

The alloy is available as sheet, plate, bar, and forging.

HP 9-4-45 Plate Data[(a)]

Condition: Bainitic[(b)]
Thickness: 0.25 inch

Properties	Temperature, F		
	RT	300	500
Tension			
F_{tu} (longitudinal), ksi	270.0	272.0	234.0
F_{tu} (transverse), ksi	260.0	271.0	235.0
F_{ty} (longitudinal), ksi	222.0	196.0	167.0
F_{ty} (transverse), ksi	224.0	197.0	166.0
e_t (longitudinal), percent in 2 in.	11.0	13.2	16.5
e_t (transverse), percent in 2 in.	10.0	11.6	15.7
E_t (longitudinal), 10^6 psi	27.1	26.8	24.6
E_t (transverse), 10^6 psi	27.7	26.6	24.9
Compression			
F_{cy} (longitudinal), ksi	249.0	219.0	187.0
F_{cy} (transverse), ksi	251.0	224.0	192.0
E_c (longitudinal), 10^6 psi	29.3	28.4	27.9
E_c (transverse), 10^6 psi	29.2	28.2	27.3
Shear			
F_{su} (longitudinal), ksi	159.0	U	U
F_{su} (transverse), ksi	159.0	U	U

Properties	Temperature, F RT	300	500
Impact			
Charpy V-notch, ft-lb	16-22	U(c)	NA(d)
Fracture Toughness			
K_{IC}, ksi $\sqrt{\text{inch}}$	(e)	U	(e)
Axial Fatigue (transverse)			
Unnotched, K_t = 1, R = 0.1(f)			
10^3 cycles, ksi	274.0	272.0	270.0
10^5 cycles, ksi	165.0	144.0	138.0
10^7 cycles, ksi	144.0	124.0	120.0
Notched, K_t = 3, R = 0.1			
10^3 cycles, ksi	190.0	190.0	168.0
10^5 cycles, ksi	70.0	68.0	68.0
10^7 cycles, ksi	55.0	60.0	60.0
Creep (transverse)			
0.5% elongation, 100 hours, ksi	NA	NA	(g)
0.5% elongation, 1000 hours, ksi	NA	NA	(g)
Stress Rupture			
Rupture, 100 hours, ksi	NA	NA	(g)
Rupture, 1000 hours, ksi	NA	NA	(g)
Stress Corrosion			
80% F_{ty}, 1000 hours max	No cracks(h)	U	U
Coefficient of Thermal Expansion			
68 to 800 F(7)	6.2×10^{-6} in./in./F		
Density(6)	0.28 lb/in.^{3}		

(a) Data are from tests conducted at Battelle under the subject contract unless otherwise indicated. In most cases, data are average values for three tests. Fatigue, creep, stress-rupture values are from data curves generated using the results of a greater number of tests.

(b) Treatment: 1 hour at 1600 F, AC; 1 hour at 1475 F; 6 hours at 475 F.

(c) Information unavailable.

(d) Information not applicable.

(e) Pop-in experienced; however, data were not within criterion for valid tests of References (4) and (5).

(f) "K_t" represents Neuber-Peterson theoretical stress-concentration factor. "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle, that is, $R = S_{min}/S_{max}$.

(g) Steel did not go to 0.5 percent elongation or to rupture at 500 F when stressed to tensile yield-strength level.

(h) Alternate immersion, 3-1/2% NaCl.

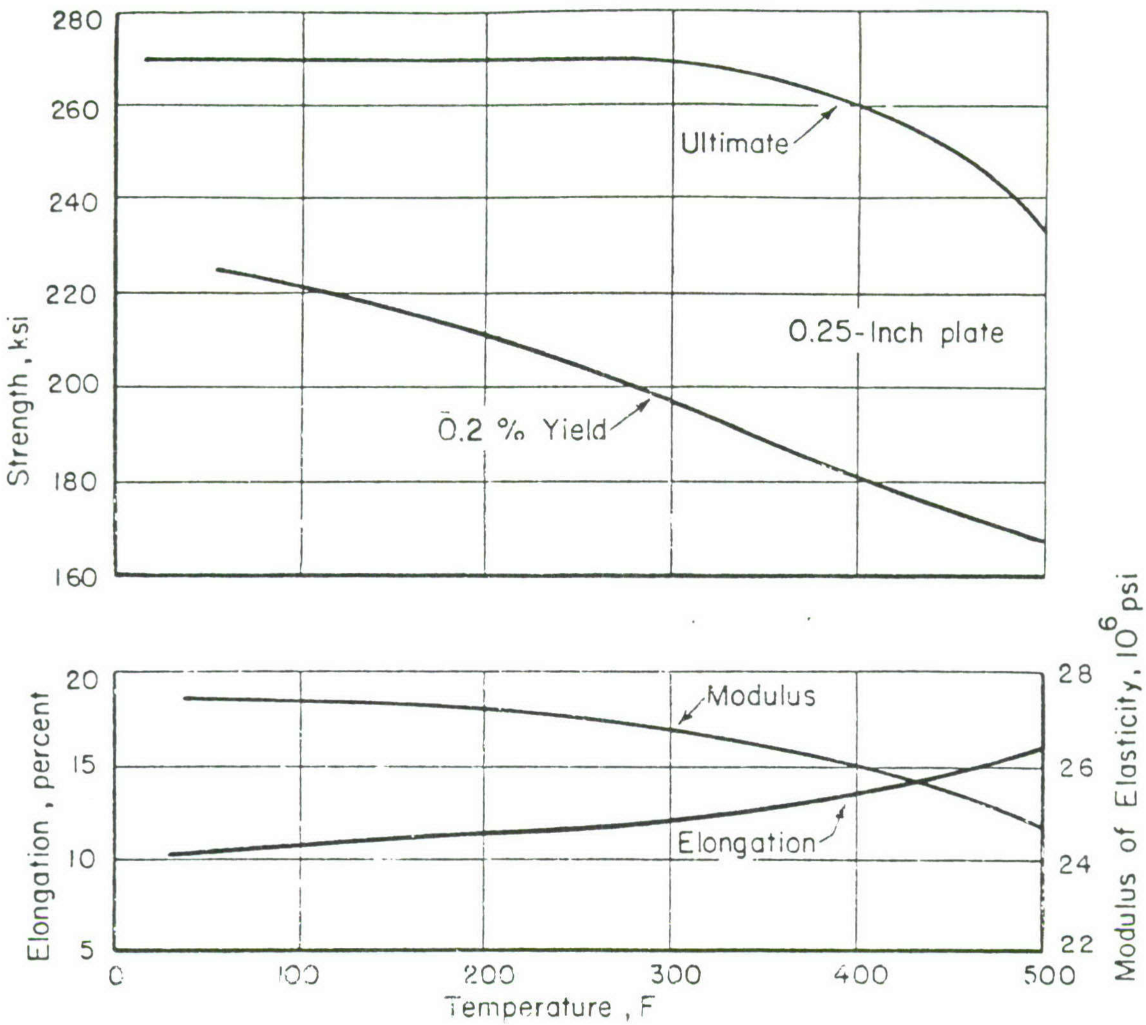


FIGURE 1. EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF HP 9-4-45 PLATE

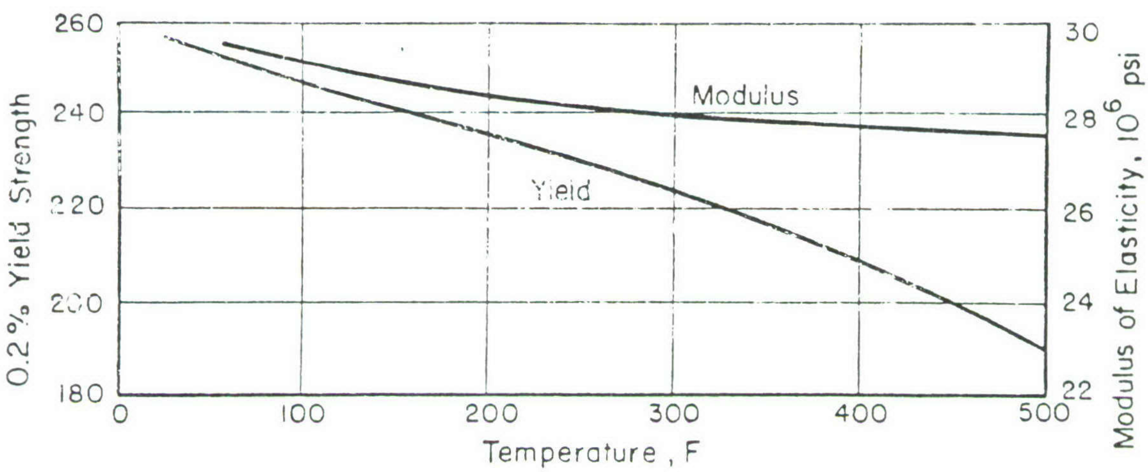


FIGURE 2. EFFECT OF TEMPERATURE ON COMPRESSION PROPERTIES OF HP 9-4-45 PLATE

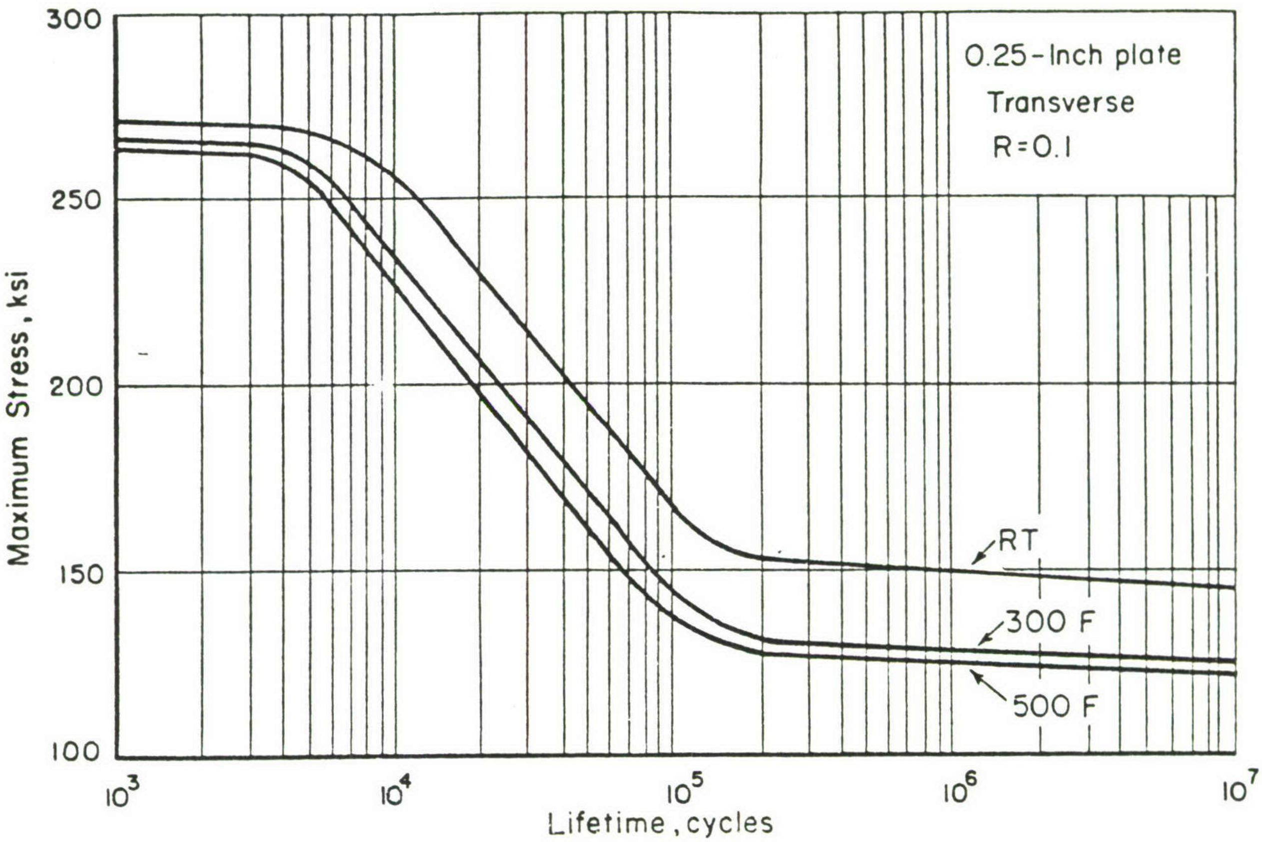


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR HP 9-4-45 PLATE AT THREE TEMPERATURES

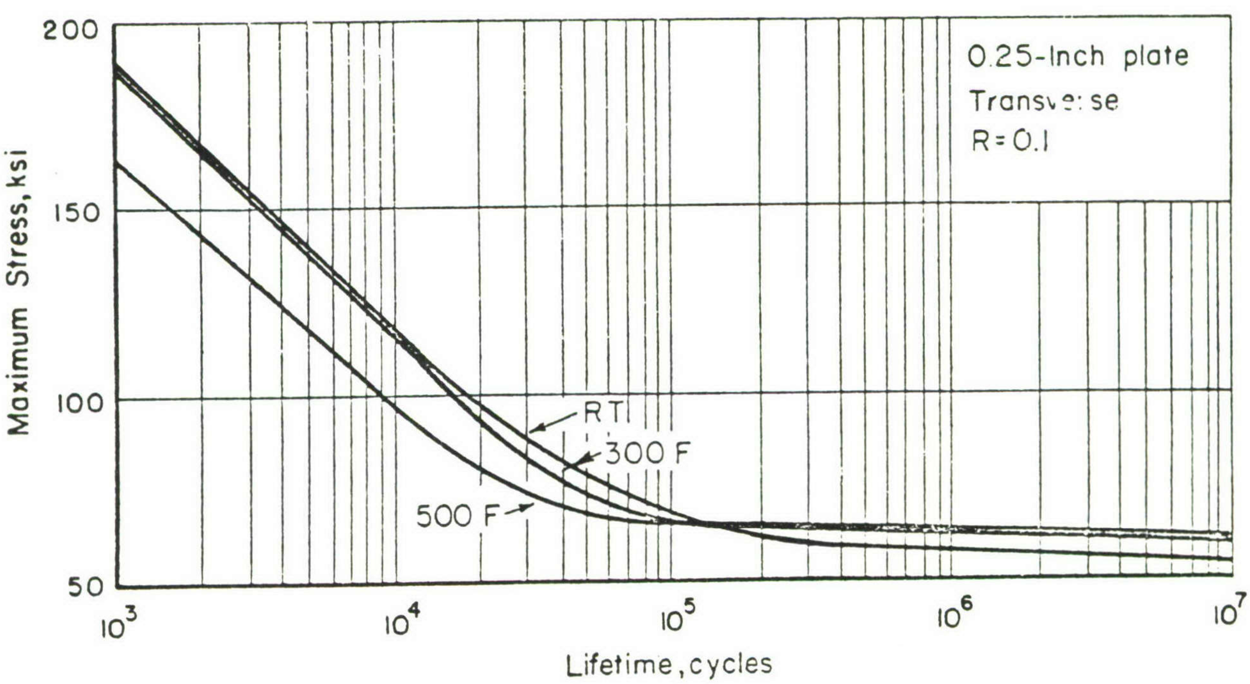


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 9-4-45 PLATE AT THREE TEMPERATURES

HP 9-4-25

The HP 9-4-25 alloy is a nickel-cobalt steel possessing excellent toughness when quenched and tempered to yield strength levels up to about 200 ksi. It is especially suitable for highly stressed structures requiring good material reliability and weldability and is intended for fabrication in the heat-treated condition for moderate and heavy sections.

This steel is sensitive to thermal-mechanical treatments and both the strength and toughness can be increased by hot-cold working.

HP 9-4-25 is available as sheet, plate, wire, rod, bar, and forgings.

HP 9-4-25 Data[a]

Condition: 1025 F Temper[b]
Thickness: 2-1/2-inch forging

Properties	Temperature, F RT	500	700	900
Tension				
F_{tu} (longitudinal), ksi	196.0	182.0	167.0	142.0
F_{tu} (transverse), ksi	194.0	181.0	167.0	141.0
F_{tu} (short transverse), ksi	197.0	--	--	--
F_{ty} (longitudinal), ksi	186.0	160.0	145.0	128.0
F_{ty} (transverse), ksi	185.0	162.0	145.0	125.0
F_{ty} (short transverse), ksi	186.0	--	--	--
e_t (longitudinal), percent in 2 in.	19.3	19.8	18.2	19.9
e_t (transverse), percent in 2 in.	18.2	17.8	18.0	18.5
e_t (short transverse), percent in 1 in.	17.7	--	--	--
RA (longitudinal), percent	66.2	68.5	71.2	73.3
E_t (longitudinal), 10^6 psi	27.8	27.6	26.2	25.6
E_t (transverse), 10^6 psi	27.6	26.9	26.3	24.2
Compression				
F_{cy} (longitudinal), ksi	196.0	169.0	155.0	131.0
F_{cy} (transverse), ksi	196.0	168.0	155.0	130.0
E_c (longitudinal), 10^6 psi	30.1	27.9	26.1	23.2
E_c (transverse), 10^6 psi	30.1	27.8	27.0	23.5
Shear[c]				
F_{su} (longitudinal), ksi	123.6	U[d]	U	U
F_{su} (transverse), ksi	124.5	U	U	U

Properties	Temperature, F			
	RT	500	700	900
Impact				
Charpy V-notch, ft-lb	35-50 [a]	U	U	U
Fracture Toughness				
K_{IC}, ksi $\sqrt{\text{inch}}$	no pop-in [f]	U	U	U
Axial Fatigue (transverse) [g]				
Unnotched, R = 0.1				
10^3 cycles, ksi	205.0	198.0	194.0	U
10^5 cycles, ksi	183.0	174.0	172.0	U
10^7 cycles, ksi	160.0	144.0	120.0	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	195.0	191.0	182.0	U
10^5 cycles, ksi	83.0	74.0	71.0	U
10^7 cycles, ksi	60.0	55.0	49.0	U
Creep (transverse)				
0.5% elongation, 100 hours, ksi	NA [d]	NA	135.0	73.0
0.5% elongation, 1000 hours, ksi	NA	NA	130.0	62.0
Stress Rupture (transverse)				
Rupture, 100 hours, ksi	NA	NA	155.0	95.0
Rupture, 1000 hours, ksi	NA	NA	148.0	70.0
Stress Corrosion				
80% F_{ty}, 1000 hours max	No cracks [b]	U	U	U
Coefficient of Thermal Expansion [i]				
68 to 800 F	6.4×10^{-6} in./in./F			
Density [i]	0.28 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise specified. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Treatment: 1 hour at 1600 F, AC; 1 hour at 1525 F, OQ; 2 + 2 hours at 1025 F.

(c) Double shear (1/4-inch pin).

(d) U = unavailable; NA = not applicable.

(e) Values from Reference (7).

(f) Fatigue-cracked single-edge-notched specimen (1 x 2 x 18 inches) tested in bending under four-point loading. No pop-in detected.

(g) "R" represents algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(h) Alternate immersion, 3-1/2% NaCl. Three-point loading bend test.

(i) Values from Reference (6).

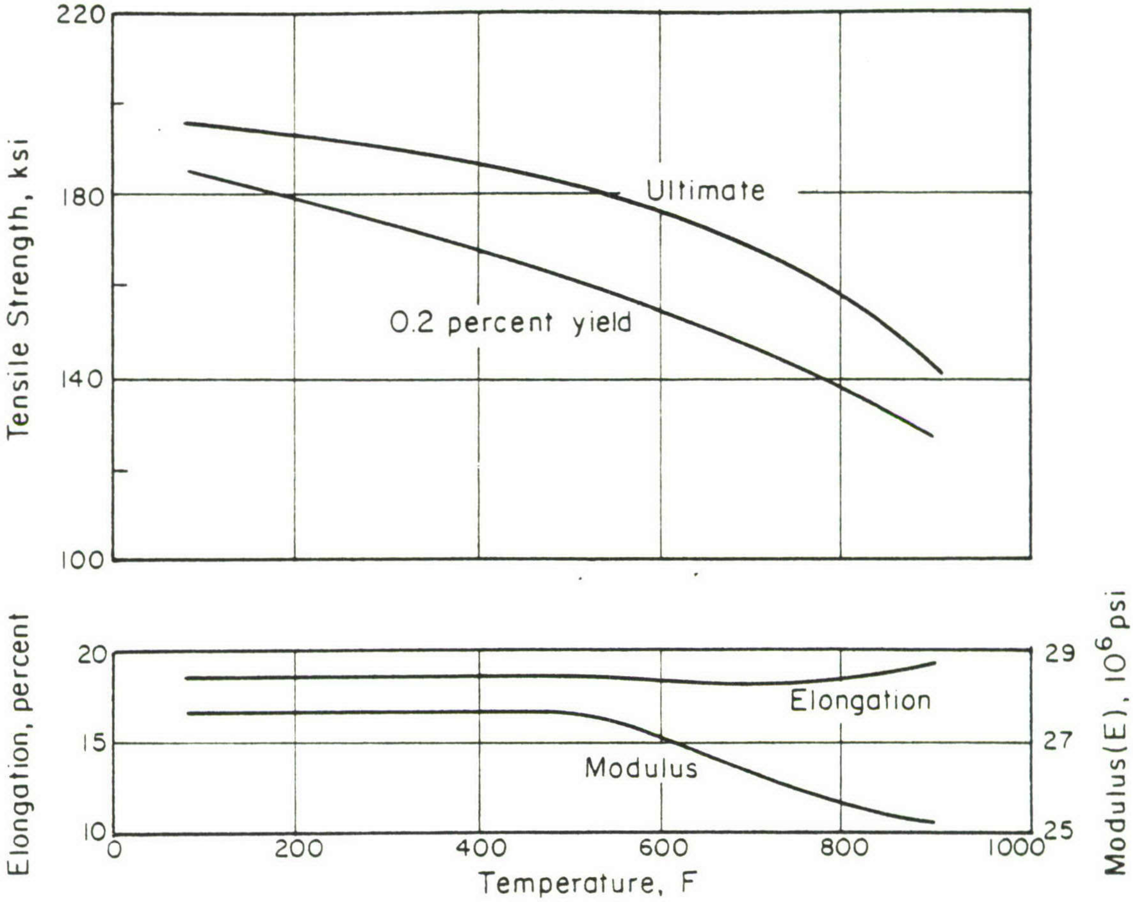


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HP 9-4-25 FORGINGS

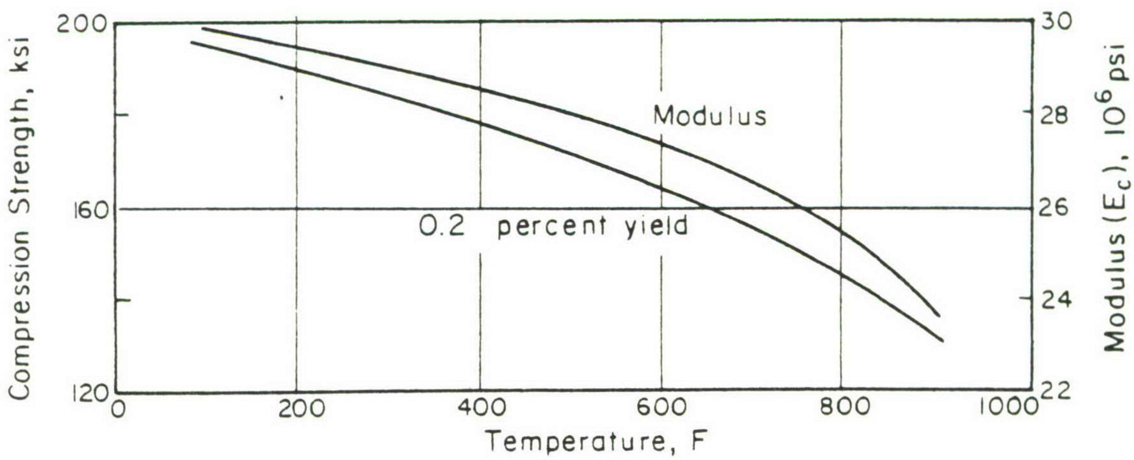


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF HP 9-4-25 FORGINGS

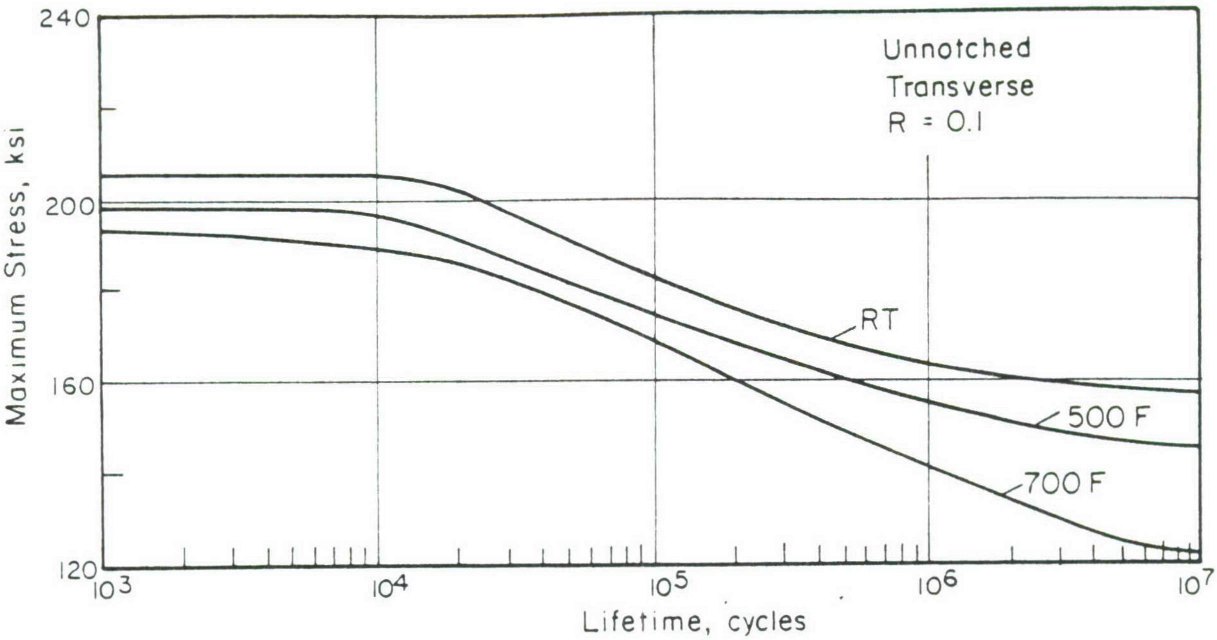


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR HP 9-4-25 FORGINGS AT THREE TEMPERATURES

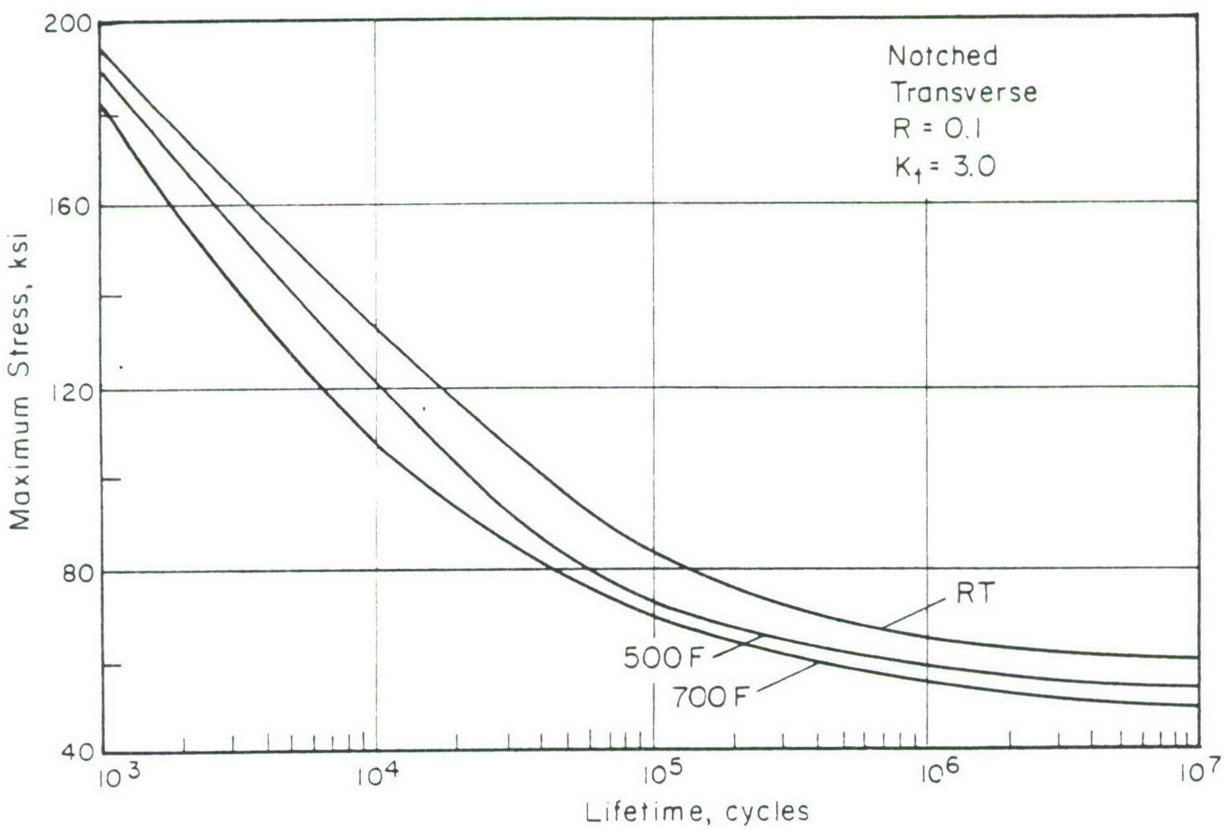


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR HP 9-4-25 FORGINGS AT THREE TEMPERATURES

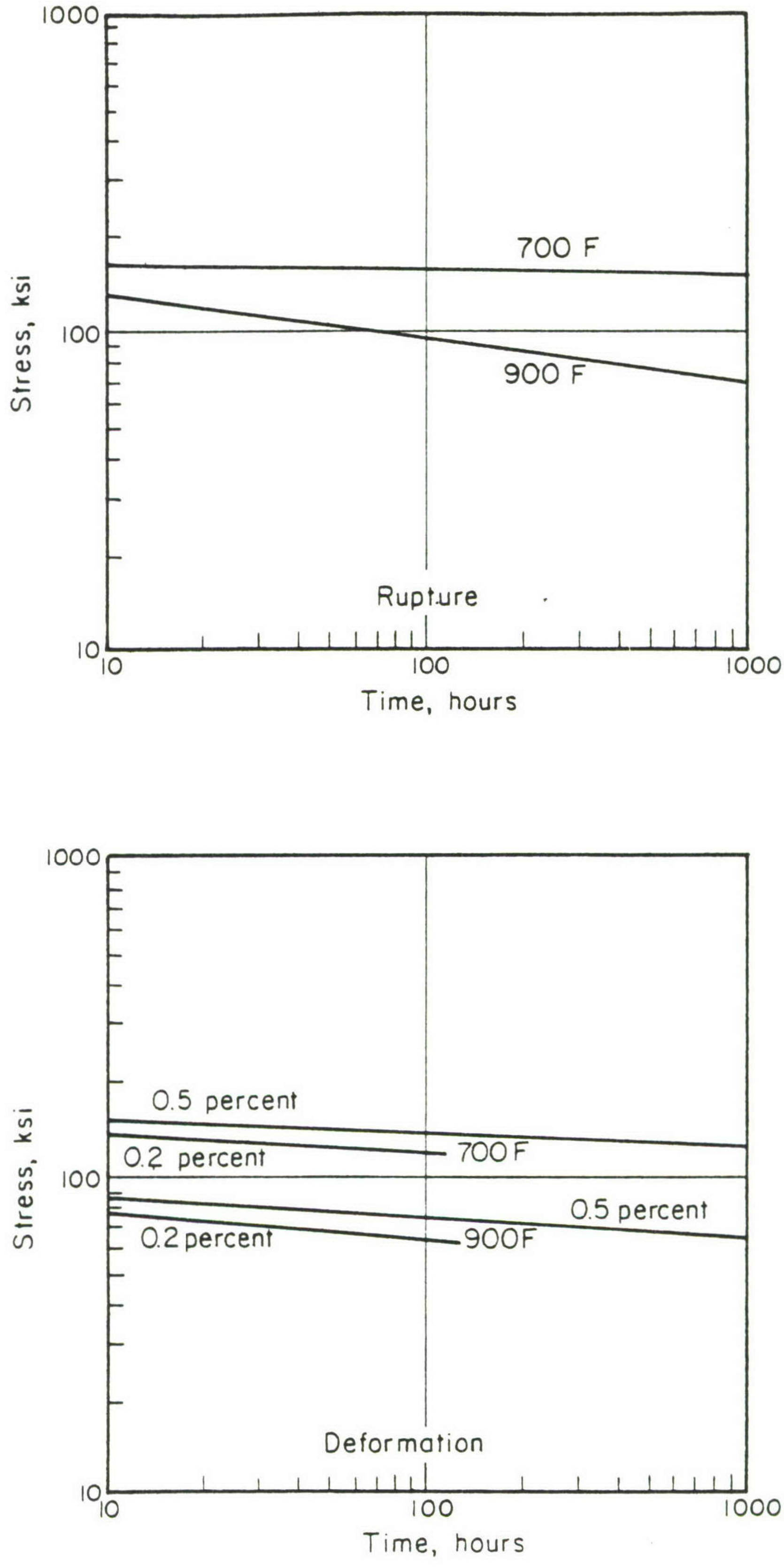


FIGURE 5. STRESS-RUPTURE AND 0.5-PERCENT PLASTIC DEFORMATION CURVES FOR HP 9-4-25 FORGINGS AT TWO TEMPERATURES

HP 9-4-45

The HP 9-4-45 alloy is a nickel-cobalt steel developed specifically to have high hardenability and good toughness. A quench and temper heat treatment may be used for sheet and thin sections to produce a tempered martensitic structure. An alternate heat treatment that results in a bainitic structure increases the section size that can be hardened. The bainitic treatment increases the toughness for all product forms.

This alloy is intended to be fabricated in the annealed condition. It can be TIG welded in the annealed condition but requires past treatment to achieve high joint efficiencies.

HP 9-4-45 is available as sheet, plate, bar, and forgings.

HP 9-4-45 Data[a]

Condition: Bainitic[b]
Thickness: 2-1/2-inch forging

Properties	Temperature, F RT	300	500
Tension			
F_{tu} (longitudinal), ksi	266.0	272.0	237.0
F_{tu} (transverse), ksi	265.0	272.0	241.0
F_{tu} (short transverse), ksi	266.0	--	--
F_{ty} (longitudinal), ksi	220.0	196.0	171.0
F_{ty} (transverse), ksi	220.0	196.0	170.0
F_{ty} (short transverse), ksi	220.0	--	--
e_t (longitudinal), percent in 2 in.	14.0	16.7	18.5
e_t (transverse), percent in 2 in.	10.5	12.5	17.8
e_t (short transverse), percent in 2 in.	13.3	--	--
RA (longitudinal), percent	54.8	55.2	68.7
RA (transverse), percent	40.2	35.7	56.2
E_t (longitudinal), 10^6 psi	27.9	26.6	24.4
E_t (longitudinal), 10^6 psi	27.6	26.6	24.8
Compression			
F_{cy} (longitudinal), ksi	246.0	211.0	184.0
F_{cy} (transverse), ksi	245.0	216.0	182.0
E_c (longitudinal), 10^6 psi	30.1	27.4	26.9
E_c (transverse), 10^6 psi	30.1	27.8	26.6
Shear[d]			
F_{su} (longitudinal), ksi	161.2	U[c]	U
F_{su} (transverse), ksi	161.5	U	U

Properties	Temperature, F RT	300	500
Impact			
Charpy V-notch, ft-lb	16-22 [e]	U	U
Fracture Toughness			
K_{IC}, ksi $\sqrt{\text{inch}}$	46.0 [f]	U	U
Axial Fatigue (transverse) [g]			
Unnotched, R = 0.1			
10^3 cycles, ksi	266.0	266.0	237.0
10^5 cycles, ksi	187.0	164.0	157.0
10^7 cycles, ksi	150.0	130.0	110.0
Notched, K_t = 3, R = 0.1			
10^3 cycles, ksi	205.0	200.0	188.0
10^5 cycles, ksi	72.0	65.0	60.0
10^7 cycles, ksi	50.0	50.0	50.0
Creep and Stress Rupture	NA [c]	NA	(h)
Stress Corrosion			
80% F_{ty}, 1000 hours max	No cracks [i]	U	U
Coefficient of Thermal Expansion [e]			
68 to 800 F	6.2×10^{-6} in./in./F		
Density [j]	0.28 lb/in.^{3}		

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.
(b) Treatment: 1 hour at 1600 F, AC; 1 hour at 1475 F; quench in salt at 475 F; 6 hours at 475 F.
(c) U = unavailable; NA = not applicable.
(d) Double shear (1/4-inch pin).
(e) Values from Reference (7).
(f) Fatigue-cracked single-edge-notched specimen (1 x 2 x 18 inches) tested in bending under four-point loading. Pop-in detected by means of a strain gage mounted on the specimen opposite the fatigue crack.

(g) "R" represents the algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(h) Material did not go to 0.2 percent elongation or to rupture at 500 F when stressed to the tensile yield strength level.

(i) Alternate immersion, 3-1/2 percent NaCl. Three-point loading bend test.

(j) Value from Reference (6).

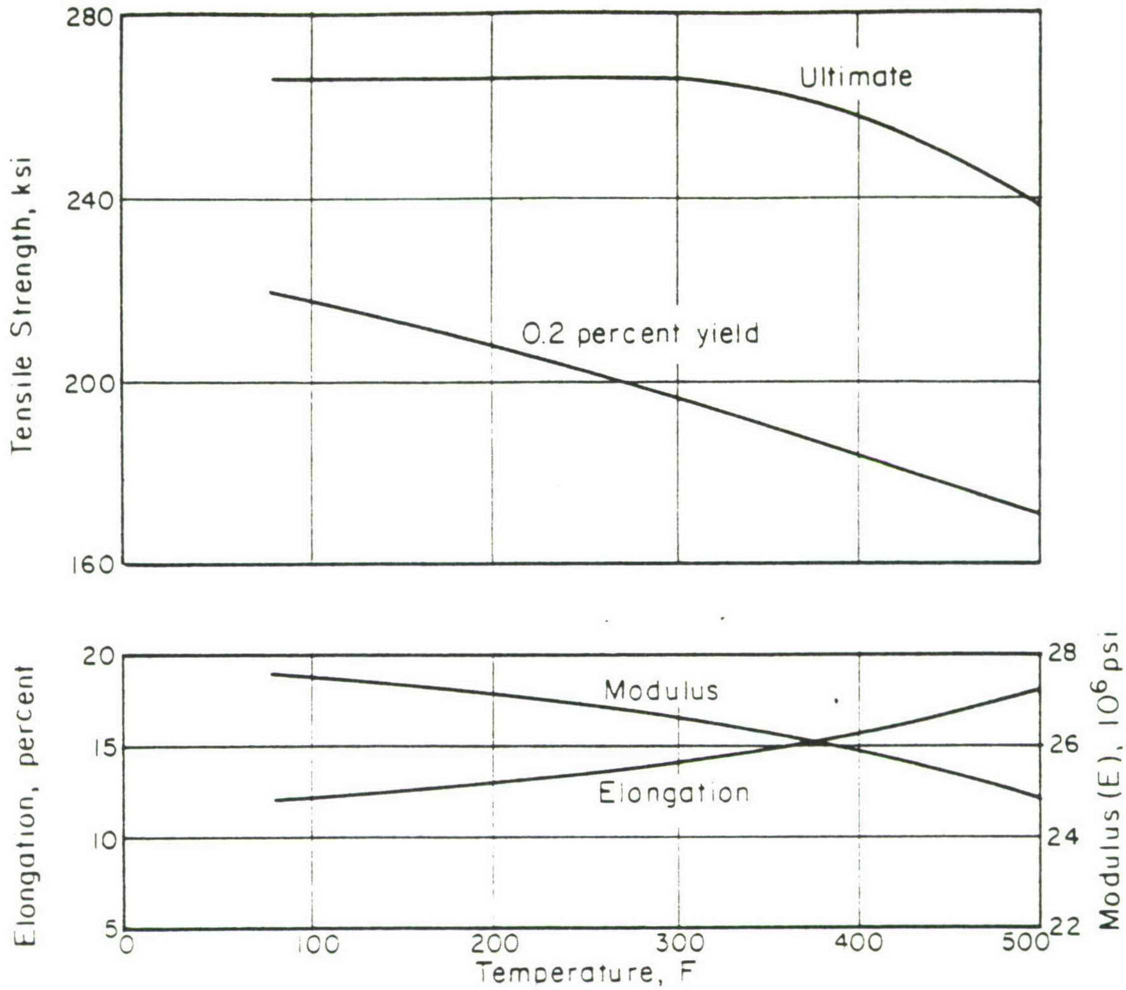


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HP 9-4-45 FORGINGS

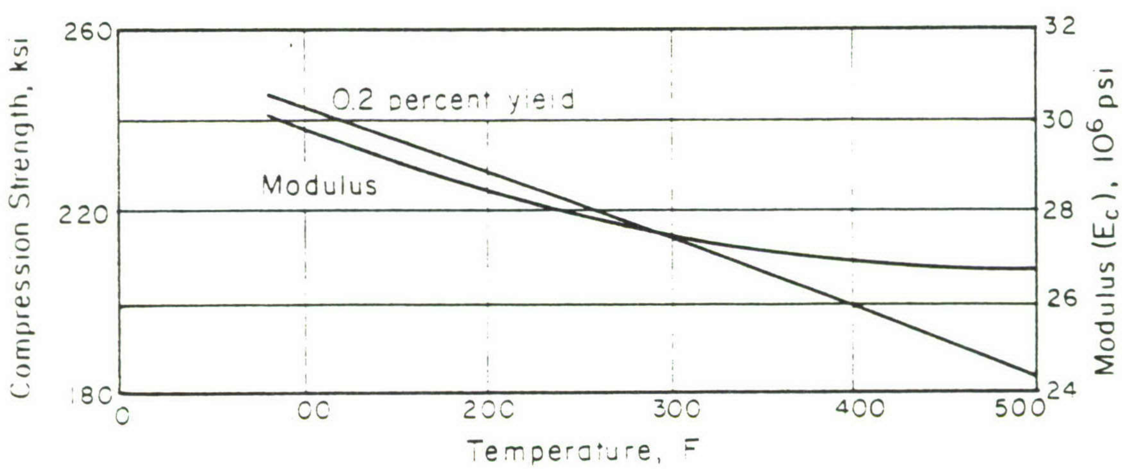


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF HP 9-4-45 FORGINGS

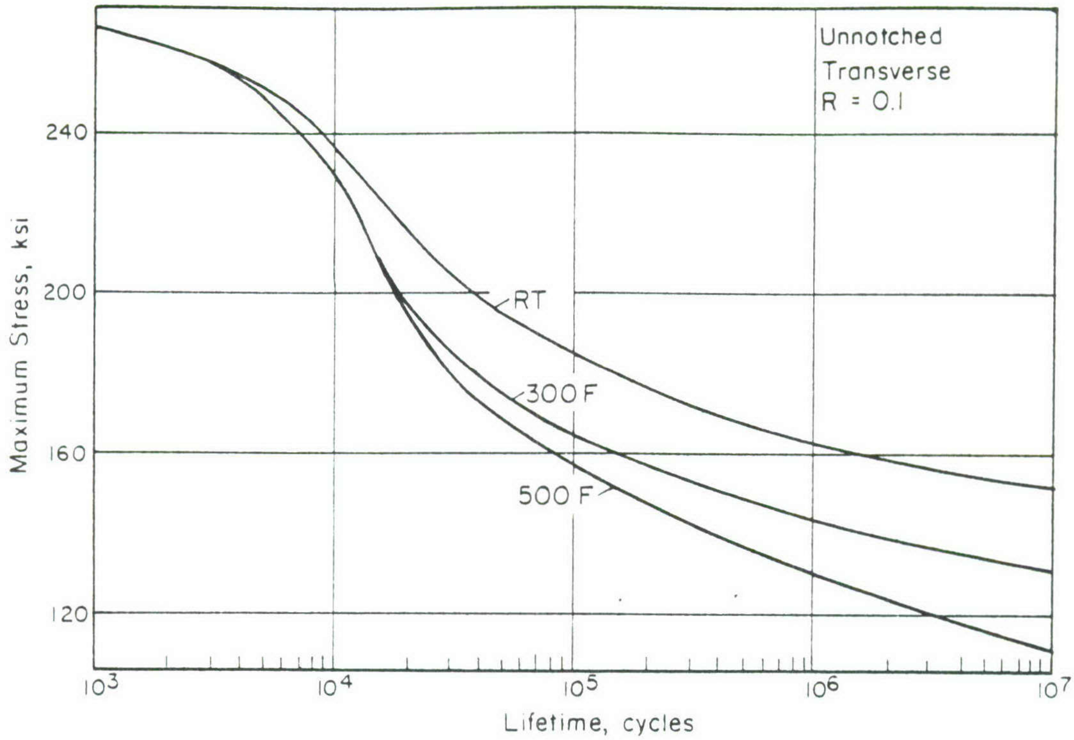


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR HP 9-4-45 FORGINGS AT THREE TEMPERATURES

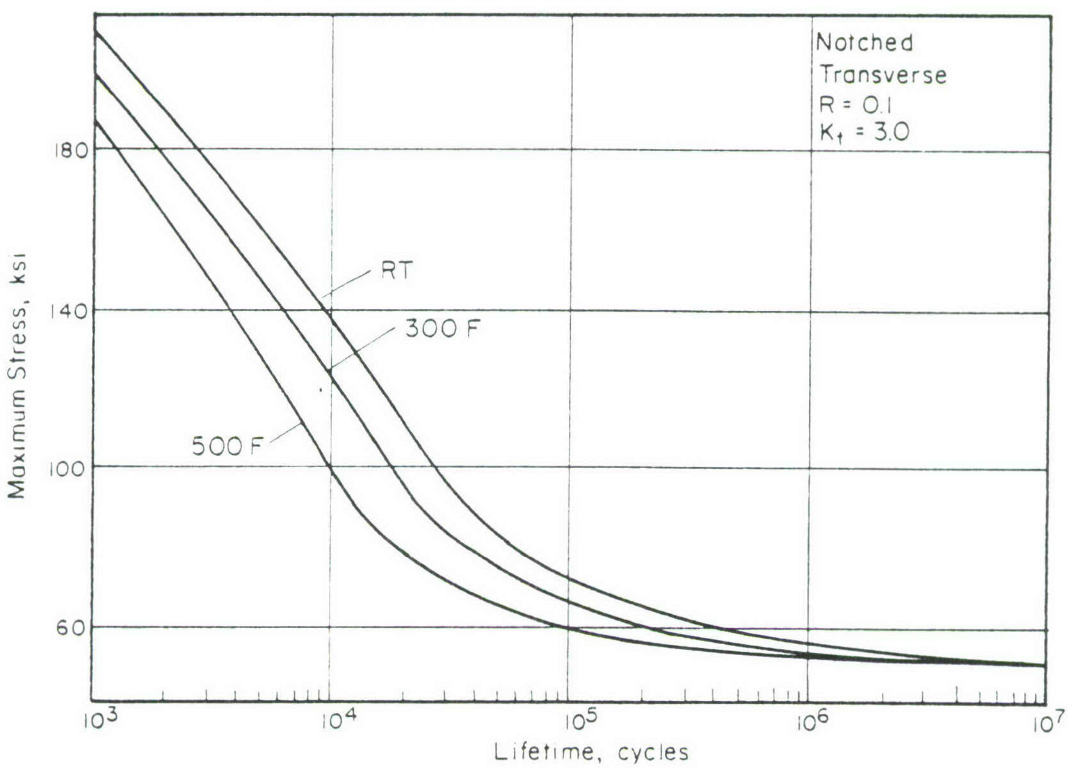


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) HP 9-4-45 FORGINGS AT THREE TEMPERATURES

AFC-77

AFC-77 is a relatively new hardenable high-strength stainless steel developed for service at temperatures ranging from subzero to 1100 F. Below a tempering temperature of 900 F, the primary strengthening mechanism depends on precipitation reactions; above 1000 F, a secondary hardening reaction occurs with the formation of intermetallic compounds. A 500 F temper produces good ductility for cold forming. For optimum machining, a 1400 F temper is recommended. For elevated-temperature service, the 1100 F temper is appropriate. Improved toughness is obtained when a 700 F tempering temperature is used.

Good weld-joint efficiencies can be obtained using the semiautomatic inert-gas-shielded tungsten-electrode (TIG) process(8).

The alloy is commercially available as bar and forging.

This alloy has been discontinued.

AFC-77 Sheet Data[(a)]

Condition: Quenched and tempered 2 + 2 hours at 700 F[(b)]
Thickness: 0.10 inch

Properties	Temperature, F			
	RT	200	400	600
Tension				
F_{tu} (longitudinal), ksi	249.0	241.0	237.0	240.0
F_{tu} (transverse), ksi	248.0	239.0	236.0	242.0
F_{ty} (longitudinal), ksi	193.0	178.0	162.0	151.0
F_{ty} (transverse), ksi	189.0	176.0	163.0	152.0
e_t (longitudinal), percent in 2 in.	11.3	11.0	11.0	11.2
e_t (transverse), percent in 2 in.	8.2	10.5	8.3	10.7
E_t (longitudinal), 10^6 psi	30.1	29.6	27.8	26.0
E_t (transverse), 10^6 psi	30.8	29.4	28.1	26.8
Compression				
F_{cy} (longitudinal), ksi	214.0	201.0	189.0	179.0
F_{cy} (transverse), ksi	217.0	202.0	190.0	178.0
E_c (longitudinal), 10^6 psi	31.5	30.9	29.6	29.4
E_c (transverse), 10^6 psi	31.8	30.9	30.1	28.9
Shear				
F_{su} (longitudinal), ksi	170.0	U	U	U
F_{su} (transverse), ksi	171.0	U	U	U

Properties	Temperature, F RT	200	400	600
Bend				
Transverse	(g)	U	U	U
Impact				
Charpy V-Notch, ft-lb[9]	13.0	U[(c)]	(500 F) 30.0	NA[(d)]
Fracture Toughness				
K_{IC}, ksi $\sqrt{\text{inch}}$	66.8[(e)]	U	(f)	NA
Axial Fatigue (transverse)				
Unnotched, $K_t = 1$, $R = 0.1$[(h)]				
10^3 cycles, ksi	268.0	264.0	256.0	U
10^5 cycles, ksi	170.0	164.0	153.0	U
10^7 cycles, ksi	156.0	132.0	127.0	U
Notched, $K_t = 3$, $R = 0.1$				
10^3 cycles, ksi	200.0	194.0	180.0	U
10^5 cycles, ksi	75.0	84.0	64.0	U
10^7 cycles, ksi	55.0	70.0	52.0	U
Creep (transverse)				
0.5% elongation, 100 hours, ksi	NA	NA	NA	(i)
0.5% elongation, 1000 hours, ksi	NA	NA	NA	(i)
Stress Rupture				
Rupture, 100 hours, ksi	NA	NA	NA	(i)
Rupture, 1000 hours, ksi	NA	NA	NA	(i)
Stress Corrosion				
80% F_{ty}, 1000 hours max	12-38 days[(j)]	U	U	U
Coefficient of Thermal Expansion				
77 to 600 F[(l)]	5.87×10^{6} in./in./F			
Density	0.282 lb/in.^{3}			

Properties	Temperature, F RT	200	400	600
Ductile-to-Brittle Bend-Tramsition Temperature, F	(g)			

(a) Data are from tests conducted at Battelle under the subject contract unless otherwise indicated. In most cases data are average values for three tests. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.

(b) Treatment: 1/4 hour at 1900 F, OQ; 1/2 hour at -100 F; 2 + 2 hours at 700 F.

(c) Information unavailable.

(d) Information not applicable.

(e) Fatigue-cracked center-notched specimens (0.080 x 3 x 12 inches).

(f) Specimens tested at 400 F failed in ductile manner. Nominal notch strength 185 ksi.

(g) Bend specimens were tempered 2 + 2 hours at 1400 F. No breaks occurred for a 4.5 T bend radius at RT, 50 F, 25 F, -25 F, and -50 F. However, the 4.5 T bend produced cracks at 0 F for a 95-degree bend angle.

(h) "K_t" represents Neuber-Peterson theoretical stress-concentration factor. "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$.

(i) Creep and stress-rupture tests were conducted at stress levels to 200 ksi at 600 F. No creep values beyond 0.1 percent were found and no specimens progressed to rupture.

(j) Alternate immersions in 3-1/2 percent NaCl. Specimens failed within range of indicated days.

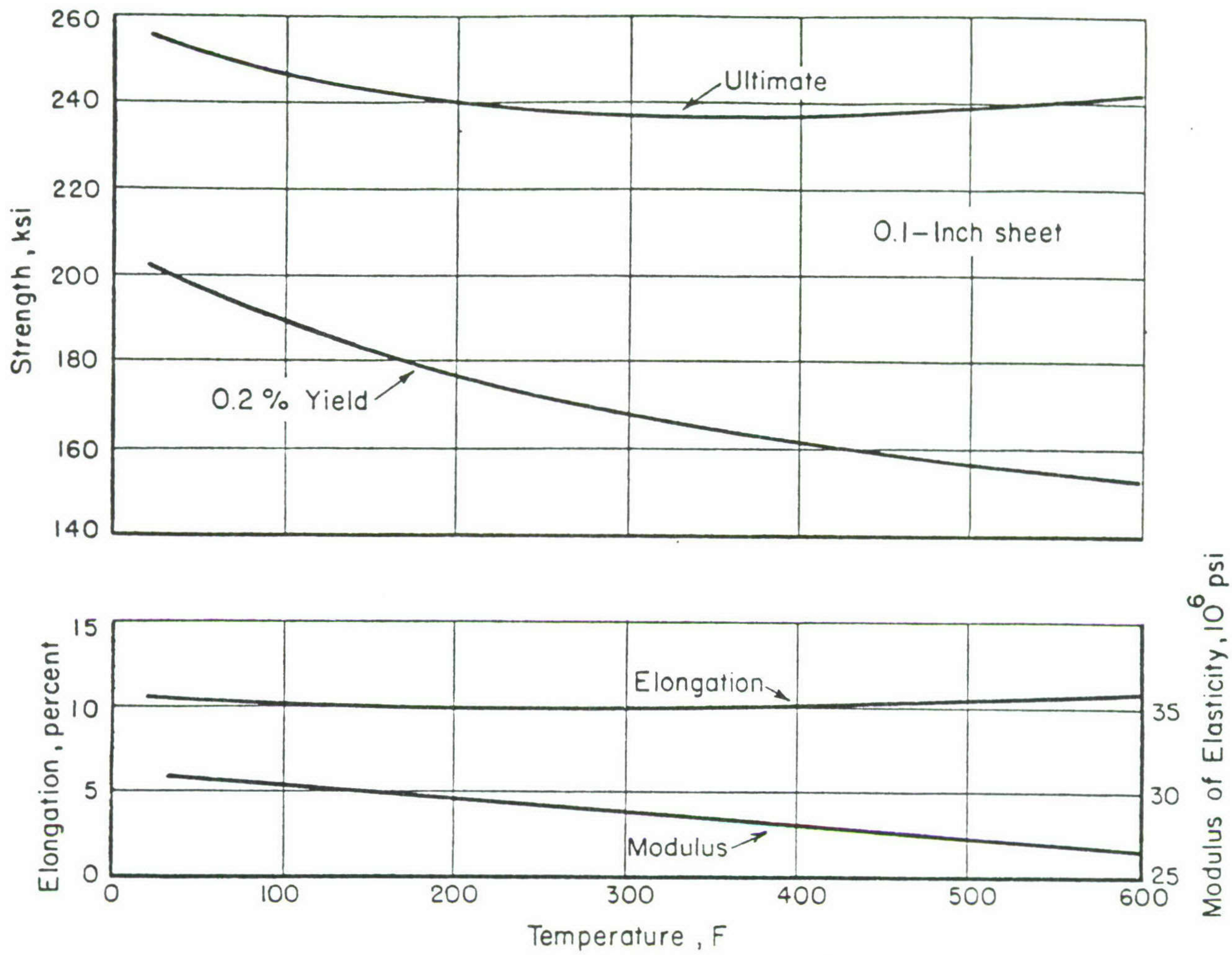


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AFC-77 SHEET (700 TEMPER)

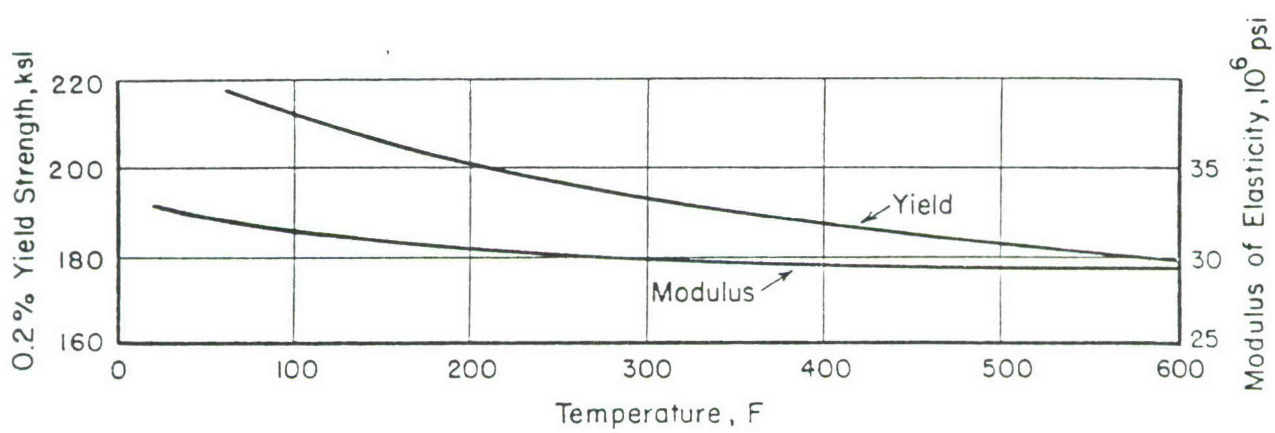


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF AFC-77 SHEET (700 F TEMPER)

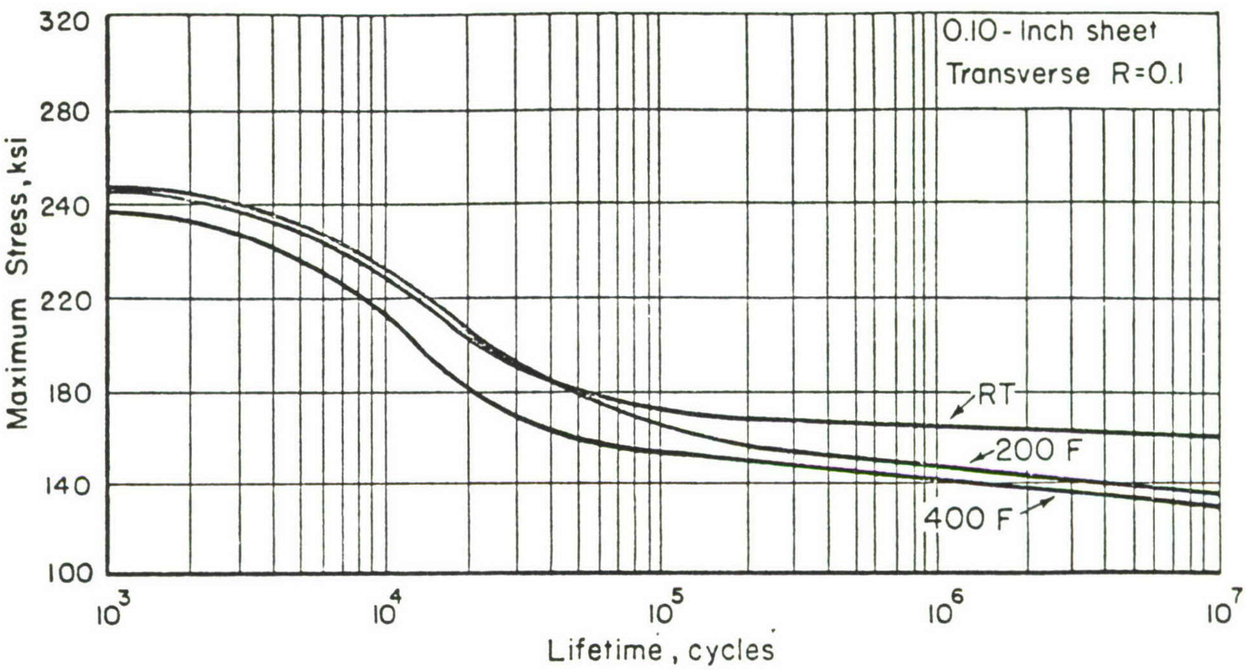


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR AFC-77 SHEET (700 F TEMPER) AT THREE TEMPERATURES

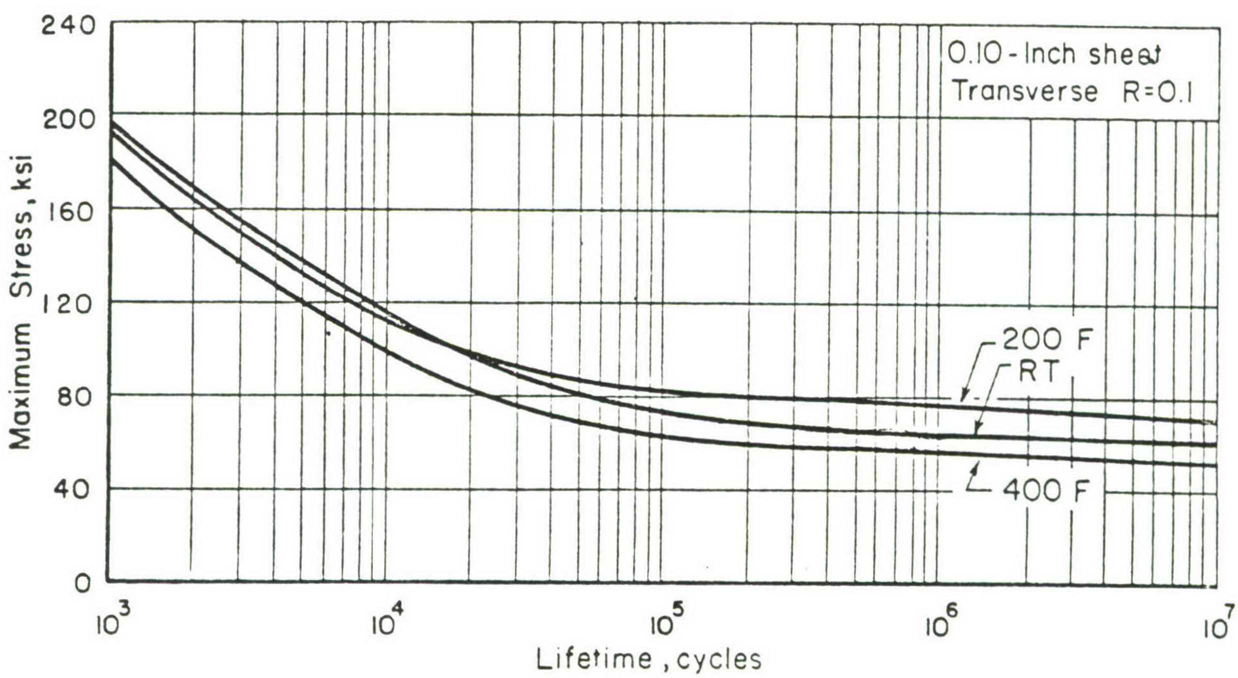


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) AFC-77 SHEET (700 F TEMPER) AT THREE TEMPERATURES

AFC-77

AFC-77 is a relatively new hardenable high-strength stainless steel developed for service at temperatures ranging from subzero to 1100 F. Below a tempering temperature of 900 F, the primary strengthening mechanism depends on precipitation reactions; above 1000 F, a secondary hardening reaction occurs with the formation of intermetallic compounds. A 500 F temper produces good ductility for cold forming. For optimum machining, a 1400 F temper is recommended. For elevated-temperature service, the 1100 F temper is appropriate. Improved toughness is obtained when a 700 F tempering temperature is used.

Good weld-joint efficiencies can be obtained using the semiautomatic inert-gas-shielded tungsten-electrode (TIG) process[6].

The alloy is commercially available as bar and forging.

This alloy has been discontinued.

AFC-77 Sheet Data[a]

Condition: Quenched and tempered 2 + 2 hours at 1100 F[b]
Thickness: 0.10 inch

Properties	Temperature, F			
	RT	600	800	1000
Tension				
F_{tu} (longitudinal), ksi	289.0	253.0	240.0	204.0
F_{tu} (transverse), ksi	286.0	249.0	237.0	203.0
F_{ty} (longitudinal), ksi	205.0	201.0	190.0	163.0
F_{ty} (transverse), ksi	201.0	198.0	187.0	163.0
e_t (longitudinal), percent in 2 in.	7.7	6.7	7.7	10.0
e_t (transverse), percent in 2 in.	7.7	6.5	7.5	10.0
E_t (longitudinal), 10^6 psi	31.2	28.1	27.7	25.6
E_t (transverse), 10^6 psi	30.3	28.0	27.5	25.0
Compression				
F_{cy} (longitudinal), ksi	242.0	224.0	215.0	193.0
F_{cy} (transverse), ksi	246.0	230.0	220.0	194.0
E_c (longitudinal), 10^6 psi	32.4	31.4	30.4	28.5
E_c (transverse), 10^6 psi	32.0	31.8	30.5	28.4
Shear				
F_{su} (longitudinal), ksi	173.0	U	U	U
F_{su} (transverse), ksi	173.0	U	U	U

Properties	Temperature, F			
	RT	600	800	1000
Bend				
Transverse	(f)	U	U	U
Impact				
Charpy V-notch, ft-lb[9]	4.0	NA[c]	NA	NA
Fracture Toughness				
K_{IC}, ksi $\sqrt{\text{inch}}$	23.1[d]	U[e]	124.0	NA
Axial Fatigue (transverse)				
Unnotched, K_t = 1, R = 0.1[g]				
10^3 cycles, ksi	292.0	266.0	260.0	U
10^5 cycles, ksi	148.0	162.0	170.0	U
10^7 cycles, ksi	130.0	124.0	116.0	U
Notched, K_t = 3, R = 0.1, ksi				
10^3 cycles, ksi	210.0	198.0	180.0	U
10^5 cycles, ksi	80.0	74.0	68.0	U
10^7 cycles, ksi	64.0	60.0	56.0	U
Creep (transverse)				
0.5% elongation, 100 hours, ksi	NA	NA	200.0	110.0
0.5% elongation, 1000 hours, ksi	NA	NA	190.0	90.0
Stress Rupture				
Rupture, 100 hours, ksi	NA	NA	NA	150.0
Rupture, 1000 hours, ksi	NA	NA	NA	130.0
Stress Corrosion				
80% F_{ty}, 1000 hours max	3-5 days[h]	U	U	U
Coefficient of Thermal Expansion				
77 to 1000 F	6.37×10^{-6} in./in./F			
Density	0.282 lb/in.^{3}			

Properties	Temperature, F RT	600	800	1000
Ductile-to-Brittle Bend-Transition Temperature, F		(f)		

(a) Data are from tests conducted at Battelle under the subject contract unless otherwise indicated. In most cases data are average values for three tests. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.

(b) Treatment: 1/4 hour at 1900 F, OQ; 1/2 hour at -100 F; 2 + 2 hours at 1100 F.

(c) Information not applicable.

(d) Fatigue-cracked center-notched specimens (0.080 x 3 x 12 inches).

(e) Information unavailable.

(f) Bend specimens were tempered 2 + 2 hours at 1400 F. No breaks occurred for a 4.5 T bend radius at RT, 50, 25, and -50 F. However, the 4.5 T bend produced cracks at 0 F for a 95-degree bend angle.

(g) "K_t" represents Neuber-Peterson theoretical stress concentration factor. "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$.

(h) Alternate immersion in 3-1/2 percent NaCl. Specimens failed within indicated number of days.

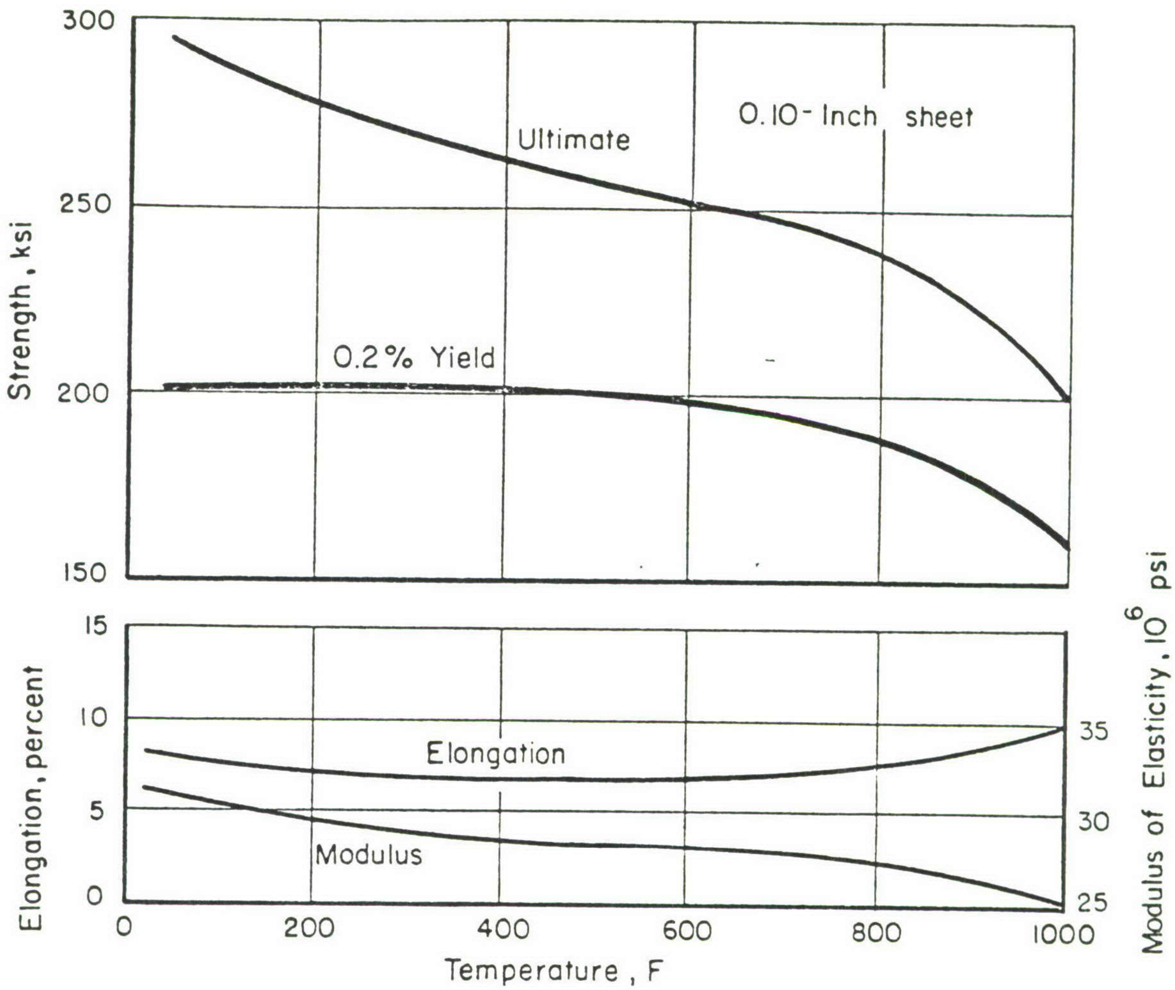


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AFC-77 SHEET (1100 F TEMPER)

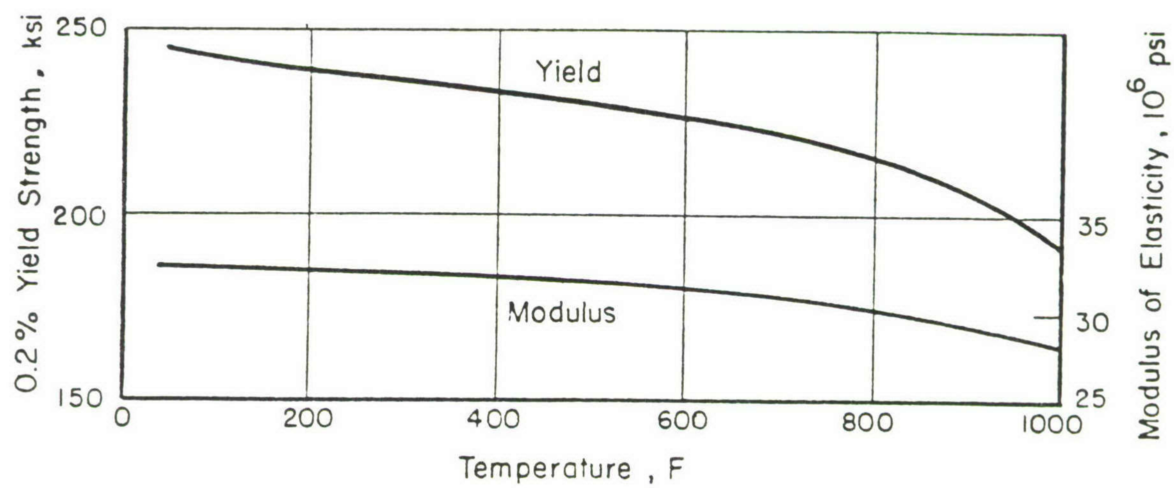


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF AFC-77 SHEET (1100 F TEMPER)

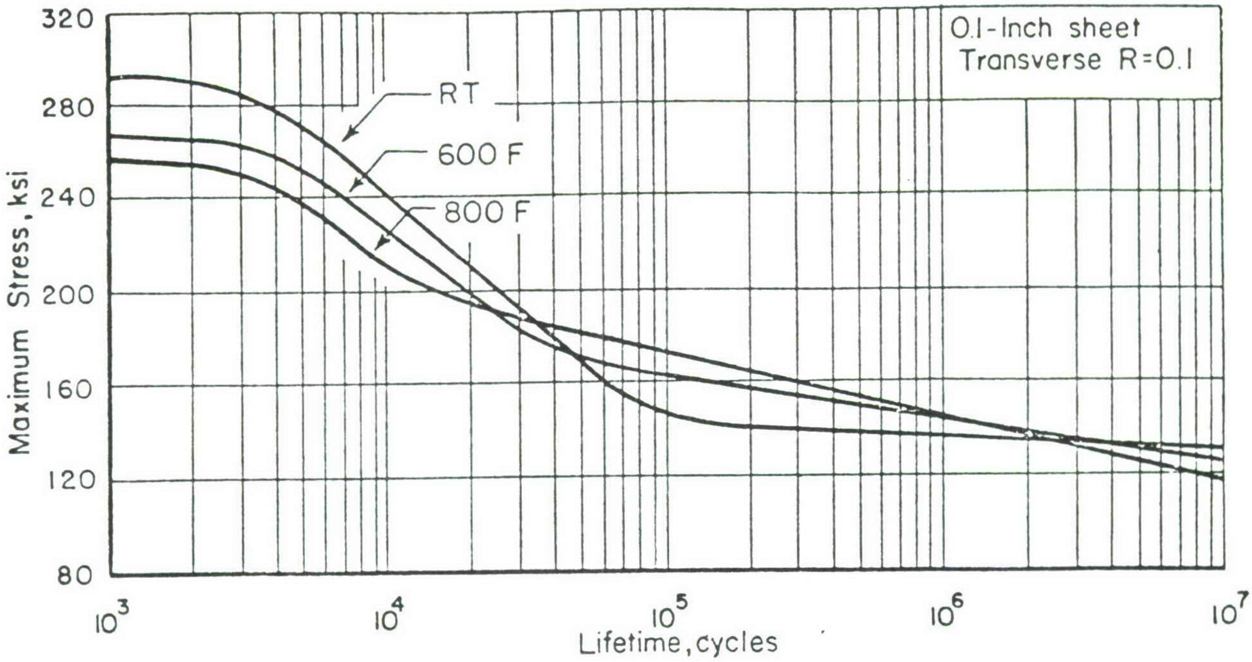


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR AFC-77 SHEET (1100 F TEMPER) AT THREE TEMPERATURES

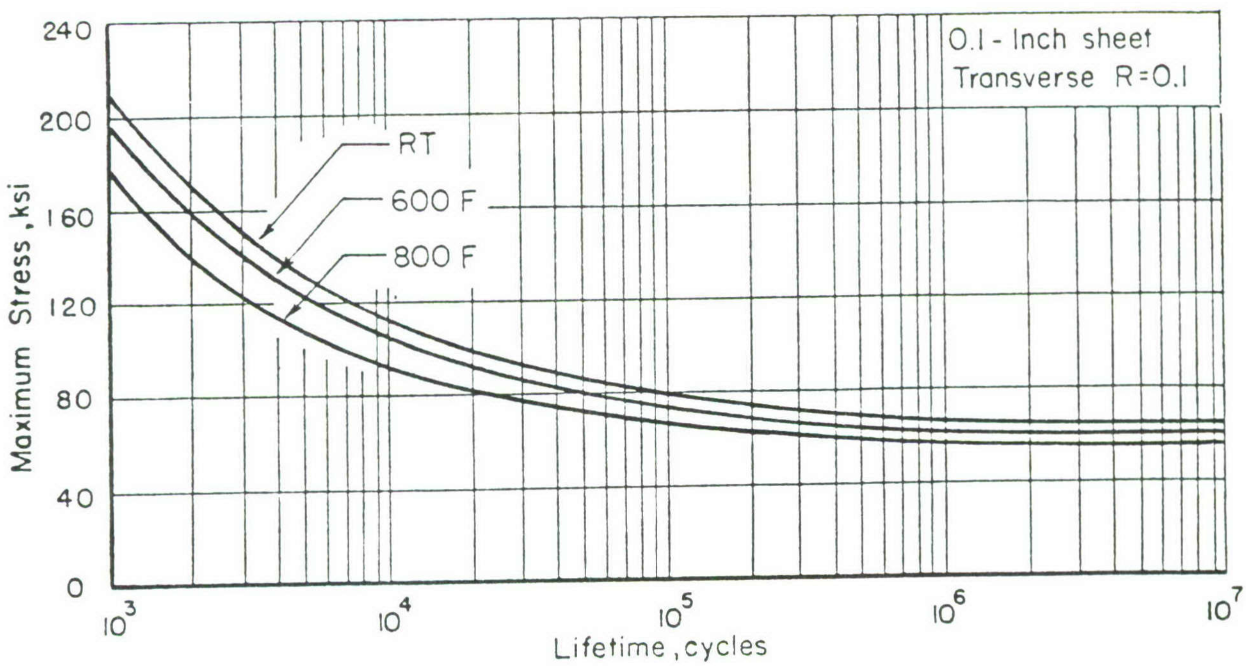


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) AFC-77 SHEET (1100 F TEMPER) AT THREE TEMPERATURES

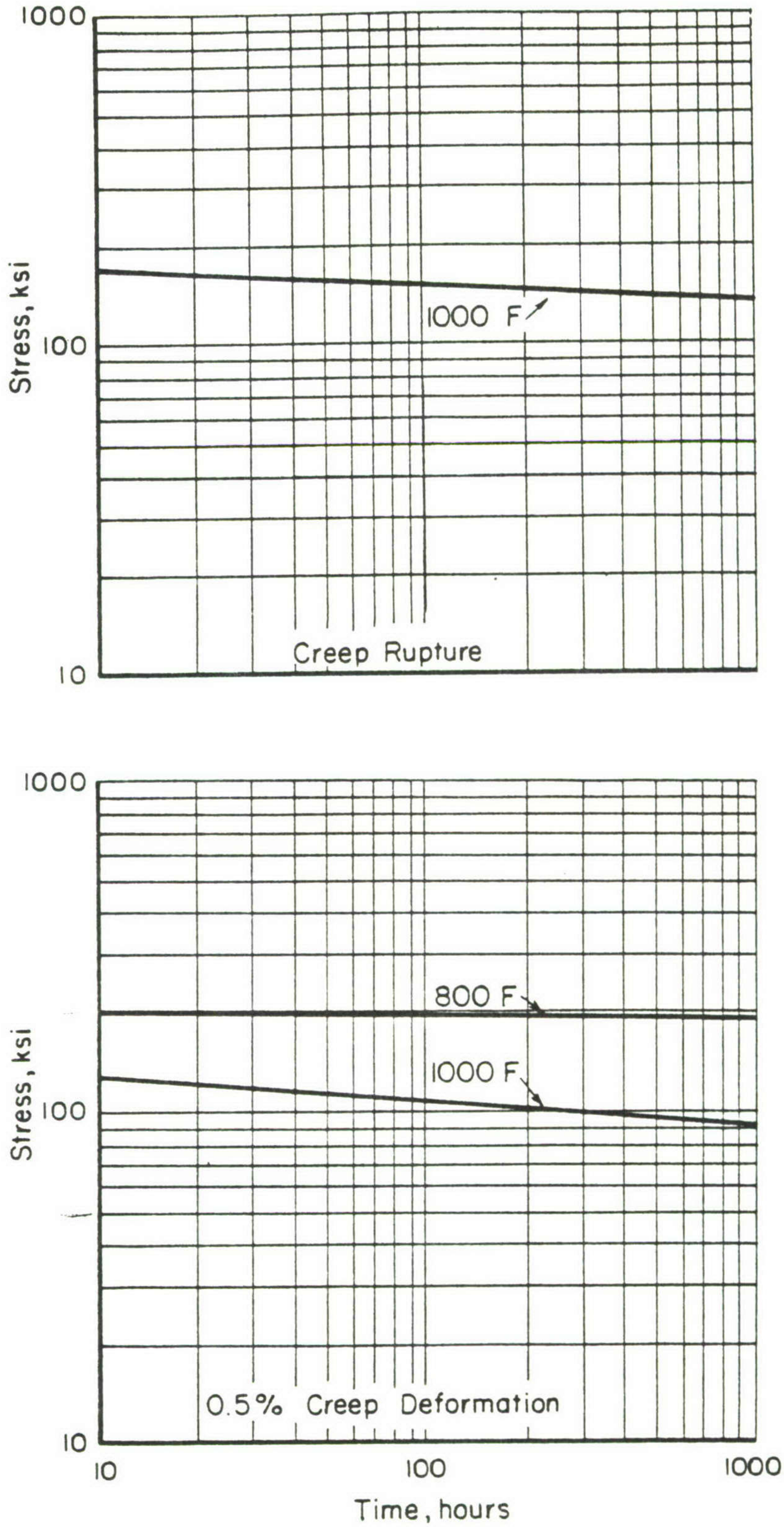


FIGURE 5. STRESS-RUPTURE AND 0.5 PERCENT DEFORMATION CURVES FOR AFC-77 SHEET (1100 F TEMPER)

62Be-38Al

This material is a recently developed alloy containing 62 percent beryllium and 38 percent aluminum. It was developed specifically for aerospace structural applications and has useful structural properties at elevated temperatures.

The alloy combines high modulus and low density with the high formability and machining characteristics of the more common magnesium alloys.

62Be-38Al has been joined by fusion welding using both TIG and electron-beam techniques. Limited tests indicate that brazing and soldering may require special techniques and handling procedures.

Observance of the same exposure criteria as used for working or handling beryllium is recommended for 62Be-38Al.

This material is currently available in sheet form 0.032 to 0.100 inch in thickness, up to 12-inch widths and 24-inch lengths.

62Be-38Al Alloy Sheet Data

Condition: Annealed[a]
Thickness: 0.062 inch

Properties	Temperature, F -320	RT	400	600	800
Tension[c]					
F_{tu} (longitudinal), ksi	60.1	50.4	39.0	22.0	24.3
F_{tu} (transverse), ksi	58.8	50.9	39.7	22.2	24.1
F_{ty} (longitudinal), ksi	41.8	36.6	30.9	21.0	21.0
F_{ty} (transverse), ksi	43.1	36.1	31.3	21.2	20.7
e_t (longitudinal), percent in 1 in.	2.4	8.1	10.6	4.0	5.0
e_t (transverse), percent in 1 in.	2.8	8.2	11.9	5.0	5.5
RA (longitudinal), percent	2.4	7.3	13.4	--	10.8
RA (transverse), percent	2.8	8.6	14.6	--	11.2
E_t (longitudinal), 10^6 psi	30.0	29.2	28.8	20.5	16.9
E_t (transverse), 10^6 psi	30.0	29.1	30.1	19.7	17.2
Compression[c]					
F_{cy} (longitudinal), ksi		34.2	27.7	24.4	14.0
F_{cy} (transverse), ksi		34.3	28.4	23.8	14.4
E_c (longitudinal), 10^6 psi		29.1	29.4	19.7	17.0
E_c (transverse), 10^6 psi		29.1	29.4	19.2	17.0

Properties	Temperature, F				
	-320	RT	400	600	800
Shear[e]					
F_{su} (longitudinal), ksi		27.2	21.5	U	10.8
F_{su} (transverse), ksi		27.0	21.6	U	10.7
Bend[e]					
Longitudinal (minimum radius), °	28.0	44.0	U	25.0	U
Transverse (minimum radius), °	32.0	39.0	U	29.0	U
Impact					
Charpy V-notch, ft-lb		U[b]	U	U	U
Fracture Toughness					
K_{IC}, ksi $\sqrt{\text{inch}}$		No pop-in	U	U	U
Axial Fatigue (transverse)[f]					
Unnotched, R = 0.1					
10^3 cycles, ksi		46.0	32.0	25.0	U
10^5 cycles, ksi		34.0	26.0	21.0	U
10^7 cycles, ksi		28.0	21.0	18.0	U
Notched, R = 0.1, K_t = 3.0					
10^3 cycles, ksi		35.0	32.0	23.0	U
10^5 cycles, ksi		21.0	20.0	15.0	U
10^7 cycles, ksi		15.0	13.0	9.0	U
Creep (transverse)[g]					
0.5% elongation, 100 hours, ksi		NA[b]	20.5	11.0	2.7
0.5% elongation, 1000 hours, ksi		NA	19.0	9.2	2.0
Stress Rupture[g]					
Rupture, 100 hours, ksi		NA	23.0	12.0	3.5
Rupture, 1000 hours, ksi		NA	21.0	10.0	2.5
Stress Corrosion[h]					
80% F_{ty}, 1000 hours max.		No cracks	U	U	U

Properties	Temperature, F				
	-320	RT	400	600	800
Coefficient of Thermal Expansion(i)					
77 to 300 F	9.2×10^6 in./in./F				
77 to 800 F	10.3×10^6 in./in./F				
Density(i)	0.0756 lb/in.^{3}				

(a) Annealed 1100 F; 24 hours; etched aqueous solution 2 percent hydrofluoric acid, 25 percent nitric acid.
(b) NA = not applicable; U = unavailable.
(c) Data at 600 F are average of triplicate tests at Battelle; all other data from Reference (11).
(d) Fatigue-cracked center-notched specimens (0.062 x 3 x 12 inches).
(e) Values from Reference (11). Bend test, 3-point simple beam; shear test, sheet single shear.
(f) "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents Neuber-Peterson theoretical stress concentration factor.
(g) Values from Battelle tests.
(h) Alternate immersion 3-1/2 percent NaCl, 3-point loading bend test.
(i) Values from Reference (20).

Note:

Bearing(e)	RT	400	600	800
F_{bru} (longitudinal), ksi	96.4	67.9	U	34.8
F_{bru} (transverse), ksi	95.7	66.9	U	31.8
F_{bry} (longitudinal), ksi	66.1	55.5	U	29.7
F_{bry} (transverse), ksi	69.5	54.9	U	30.2

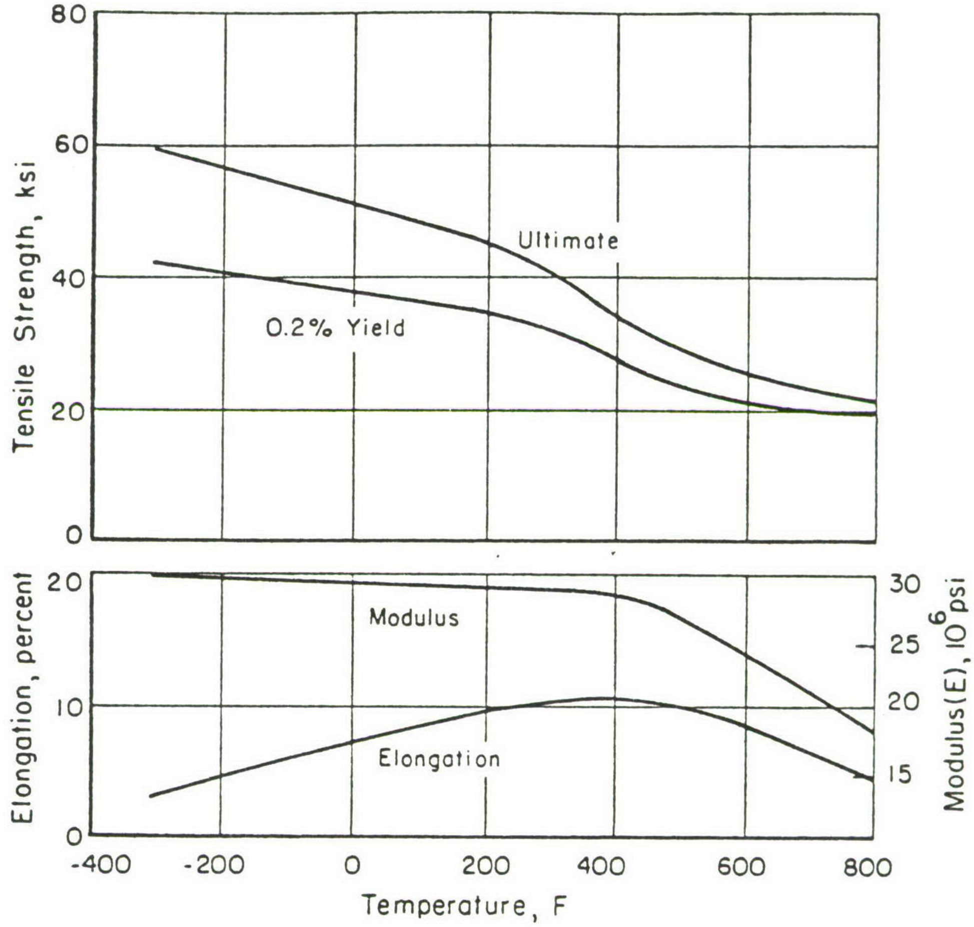


FIGURE 1. EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF 62Be-38Al ALLOY SHEET

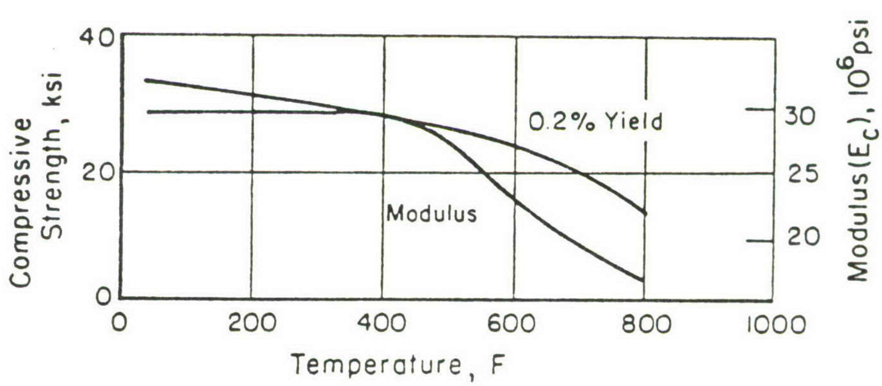


FIGURE 2. EFFECT OF TEMPERATURE ON COMPRESSION PROPERTIES OF 62Be-38Al ALLOY SHEET

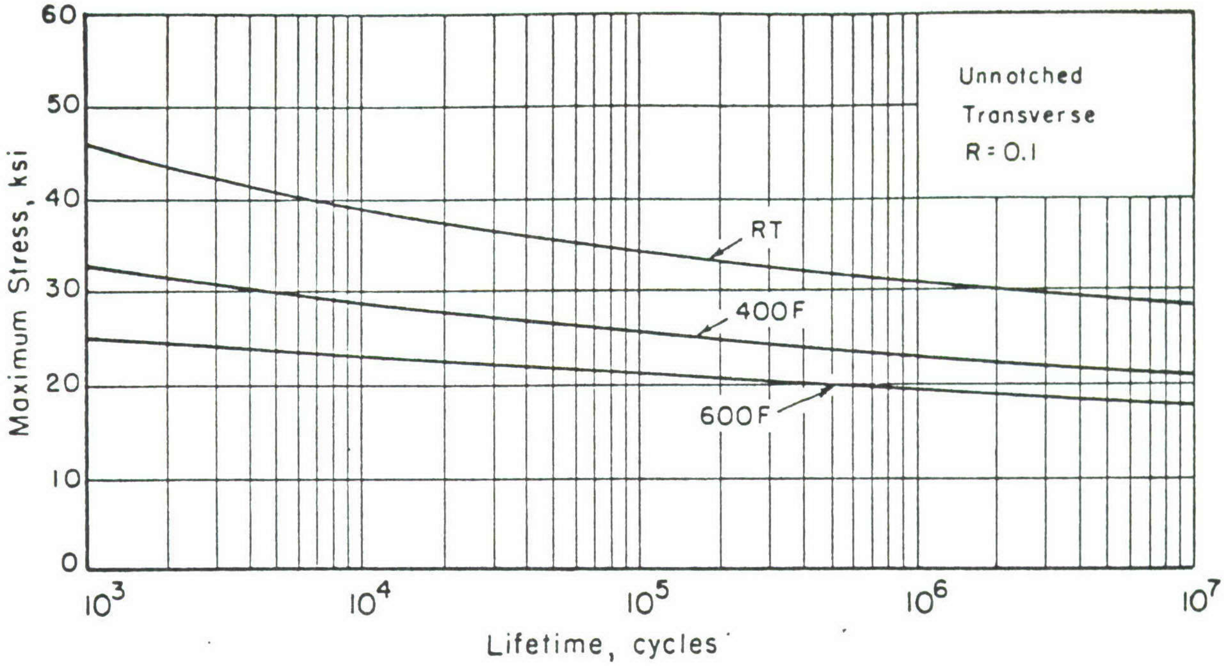


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 62Be-38Al ALLOY SHEET

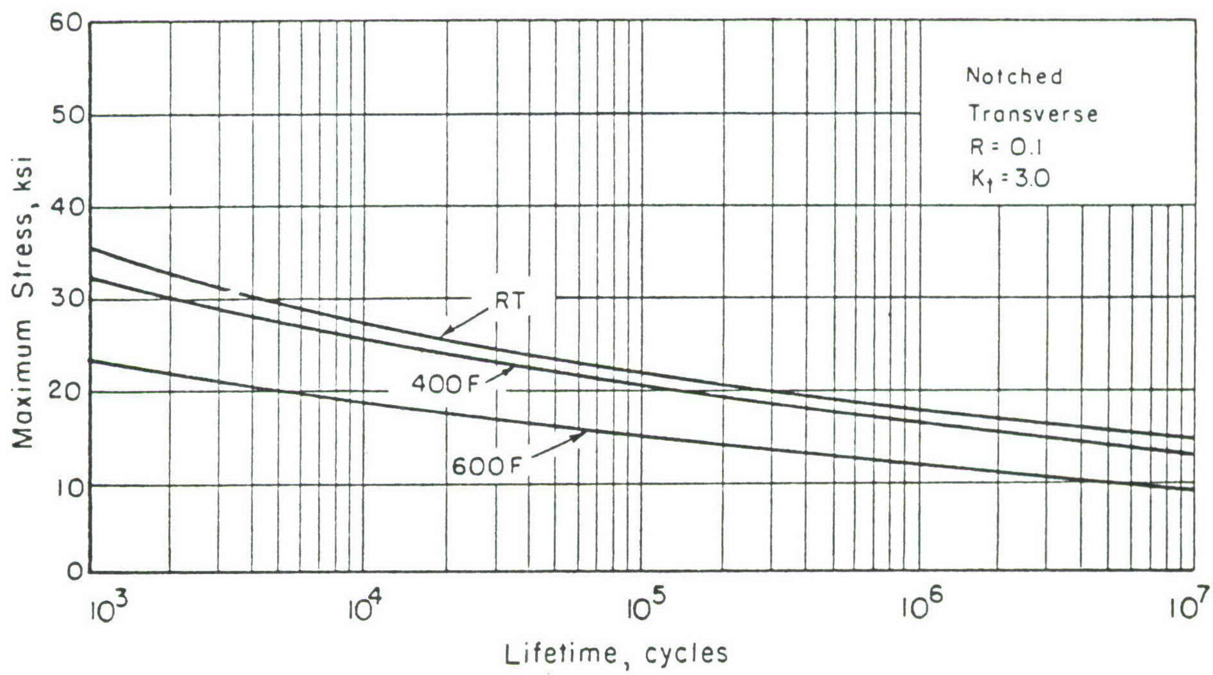


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 62Be-38Al ALLOY SHEET

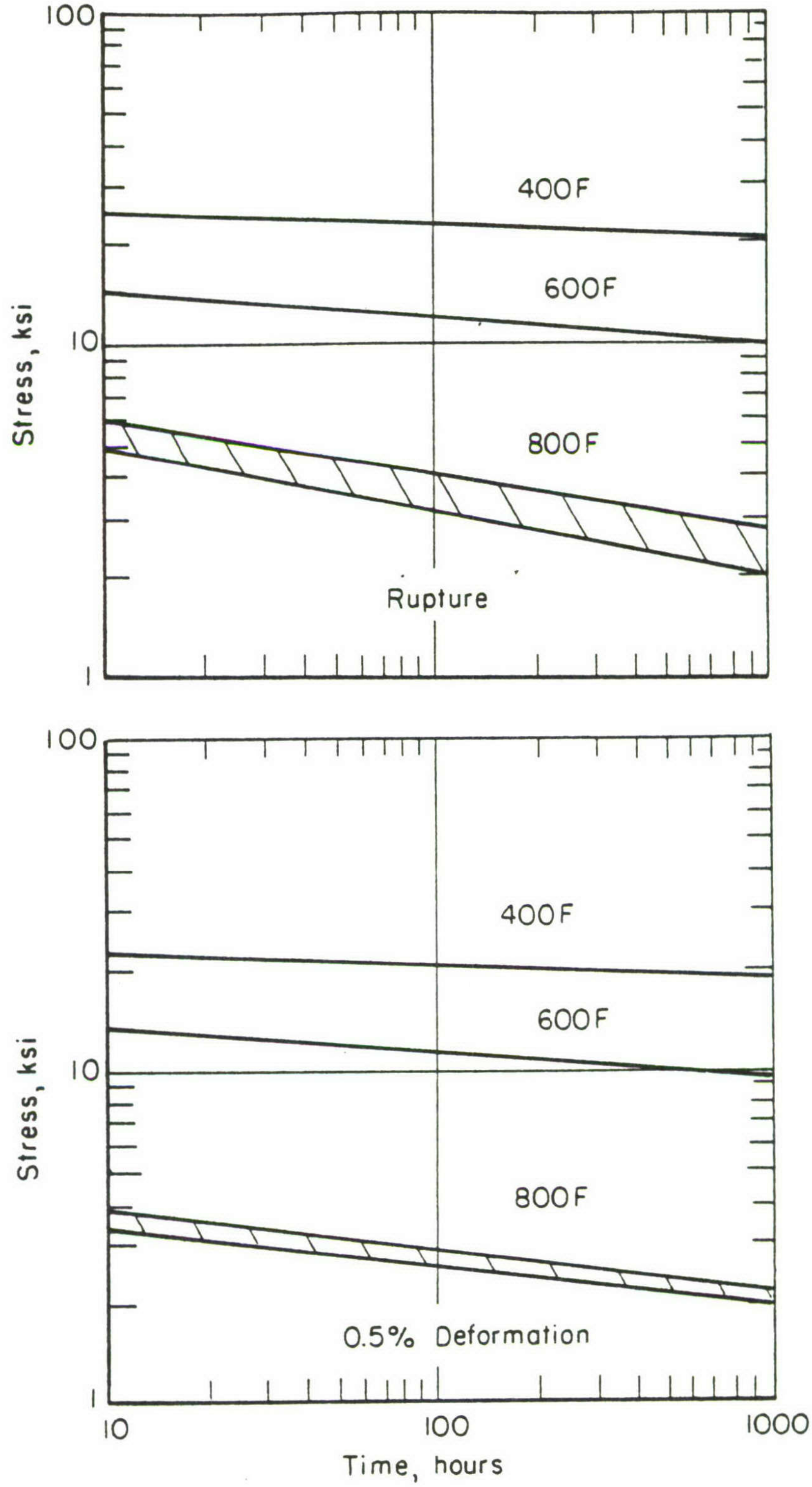


FIGURE 5. STRESS-RUPTURE AND 0.5 PERCENT DEFORMATION CURVES FOR 62 Be-38Al ALLOY SHEET

Beryllium Sheet (Cross-Rolled)

Beryllium is a light-weight, high-modulus metal that is advantageous for specific aerospace applications. Beryllium does not have the ductility of the more common light metals; however, current production of this material by powder metallurgical techniques results in a metal that can be used.

This material has limited formability at room temperature; however, formability is considerably increased at elevated temperature.

Brazing, mechanical joining, and welding techniques have been used to a limited extent in fabricating beryllium. For each method of joining, specific, detailed procedures must be followed.

Beryllium is available in vacuum-hot-pressed blocks, cross-rolled sheet, strip, plate, wire, and as extrusions and forgings.

Particles of beryllium and its compounds are toxic. Special precautions must be taken in that no inhalation occurs.

Beryllium Sheet Data[(a)]

Condition: Cross-rolled[(b)]
Thickness: 0.020-0.063 inch

Properties	Temperature, F			
	RT	400	600	800
Tension				
F_{tu} (longitudinal), ksi	75.0	57.9	46.0	37.3
F_{tu} (transverse), ksi	76.3	56.0	45.9	37.3
F_{ty} (longitudinal), ksi	55.4	48.9	41.2	36.6
F_{ty} (transverse), ksi	54.0	47.8	41.4	36.6
e_t (longitudinal), percent in 1 in.	8.0	41.0	43.0	23.0
e_t (transverse), percent in 1 in.	14.0	35.0	40.0	22.0
RA (longitudinal), percent	U[(c)]	U	U	U
E_t (longitudinal, 10^6 psi	43.1	39.8	36.8	31.3
E_t (transverse), 10^6 psi	41.6	40.2	36.1	31.6
Compression				
F_{cy} (longitudinal), ksi	58.3	52.7	48.0	39.8
F_{cy} (transverse), ksi	57.8	52.7	46.2	39.3
E_c (longitudinal), 10^6 psi	42.5	39.8	39.3	38.1
E_c (transverse), 10^6 psi	40.8	40.7	40.0	38.7

Properties	Temperature, F RT	400	600	800
<u>Shear</u>				
F_{su} (longitudinal), ksi	34.8	U	U	U
F_{su} (transverse), ksi	33.4	U	U	U
<u>Bend</u>				
Minimum radius	Fracture	U	32T	10T
<u>Impact</u>				
Charpy V-notch	U(c)	U	U	U
<u>Fracture Toughness</u>				
K_{IC}, ksi $\sqrt{\text{inch}}$	No pop-in(d)	U	U	U
<u>Axial Fatigue</u> (transverse)				
Unnotched, R = 0.1(e)				
10^3 cycles, ksi	76.0	67.0	58.0	U
10^5 cycles, ksi	61.0	56.0	49.0	U
10^7 cycles, ksi	50.0	43.0	40.0	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	67.0	67.0	67.0	U
10^5 cycles, ksi	33.0	31.0	27.0	U
10^7 cycles, ksi	28.0	20.0	17.0	U
<u>Creep</u> (transverse)				
0.5% elongation, 100 hours, ksi	NA(c)	43.0	42.0	20.0
0.5% elongation, 1000 hours, ksi	NA	42.0	40.0	15.0
<u>Stress Rupture</u> (transverse)				
Rupture, 100 hours, ksi	NA	48.0	42.0	27.0
Rupture, 1000 hours, ksi	NA	44.0	39.0	20.0
<u>Stress Corrosion</u>				
80% F_{ty}, 1000 hours max.	No Cracks(f)	U	U	U

Properties	Temperature, F RT	400	600	800
Coefficient of Thermal Expansion				
77 to 212 F	6.4×10^{6} in./in./F[g]			
77 to 800 F	8.3×10^{6} in./in./F[h]			
Density				
	0.066 lb/in.^{3}[g]			

(a) Values are from tests conducted at Battelle under the subject contract unless otherwise indicated. In most cases, values are average of triplicate test. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.

(b) All specimens etched: 20 percent nitric acid, 1 percent sulfuric acid by volume, water balance (temperature 80 to 90 F) to remove any surface damage or residual stresses caused by machining.

(c) NA = not applicable; U = unavoidable.

(d) Fatigue-cracked center-notched specimen 3 x 12 inch. Fracture data not reliable--specimens failed at grip ends and in bolt holes.

(e) "R" represents algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents Neuber-Peterson theoretical stress concentration factor.

(f) Alternate immersion, 3-1/2 percent NaCl, 3-point loading bend test.

(g) Values from Reference (13).

(h) Values from Reference (12).

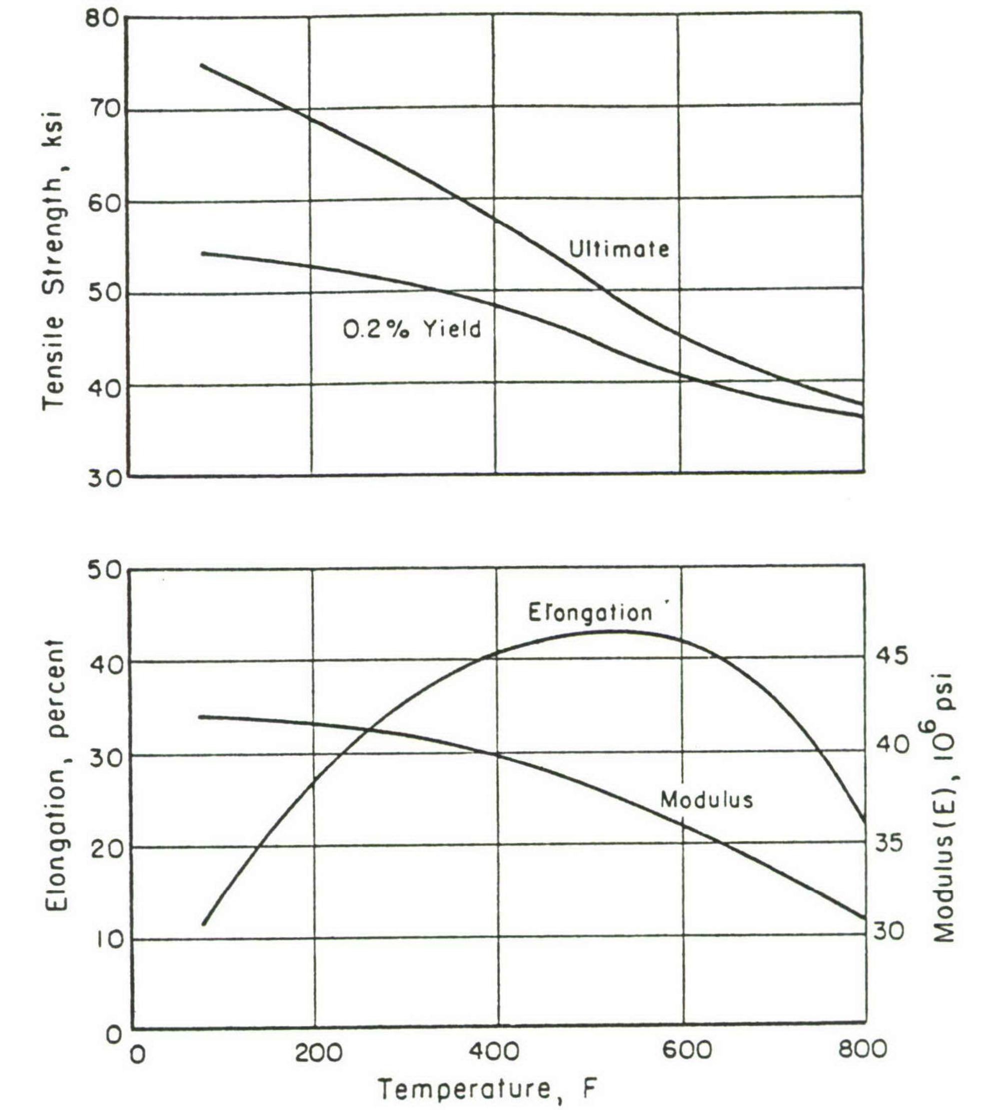


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CROSS-ROLLED BERYLLIUM SHEET

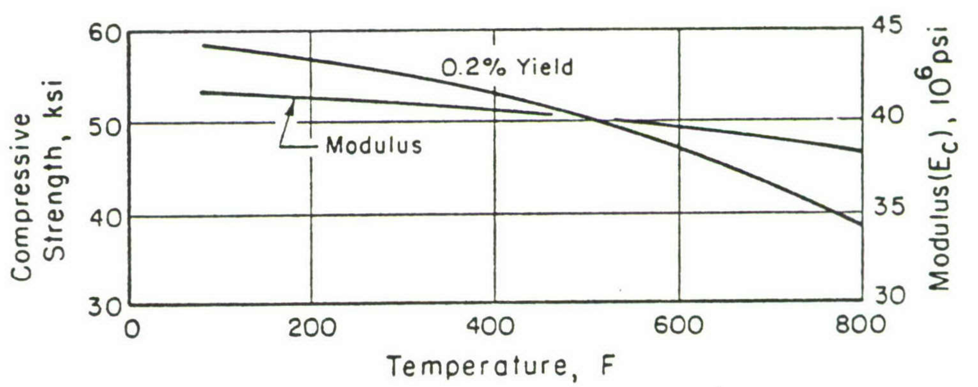


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF CROSS-ROLLED BERYLLIUM SHEET

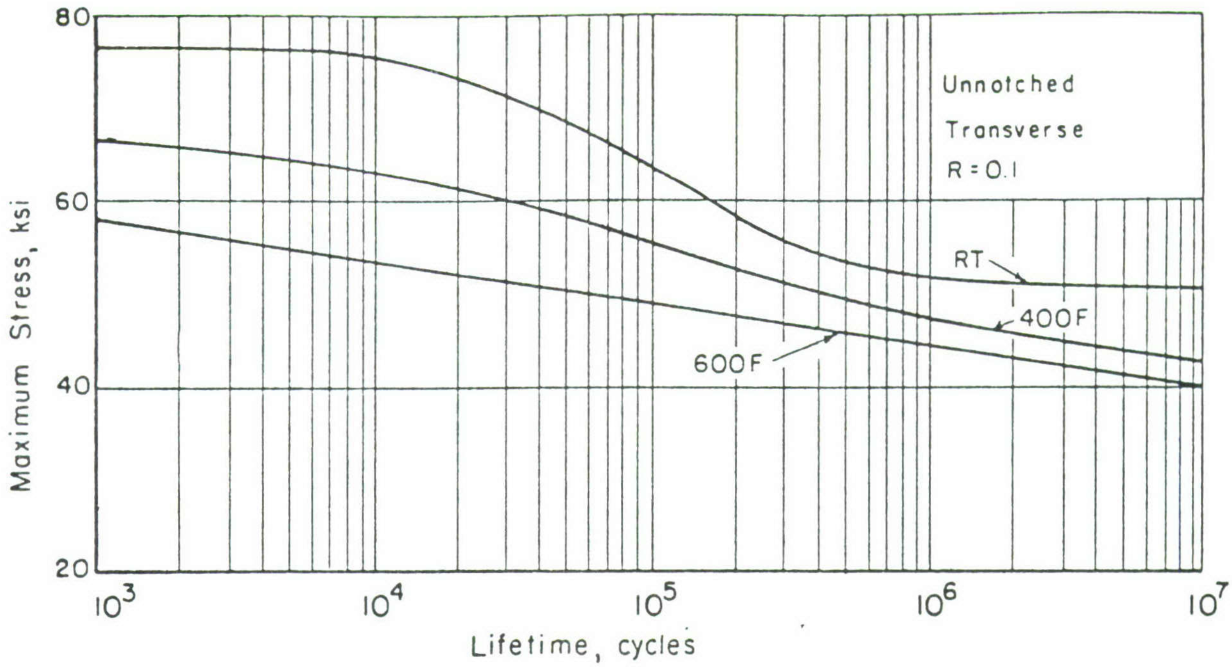


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR CROSS-ROLLED BERYLLIUM SHEET

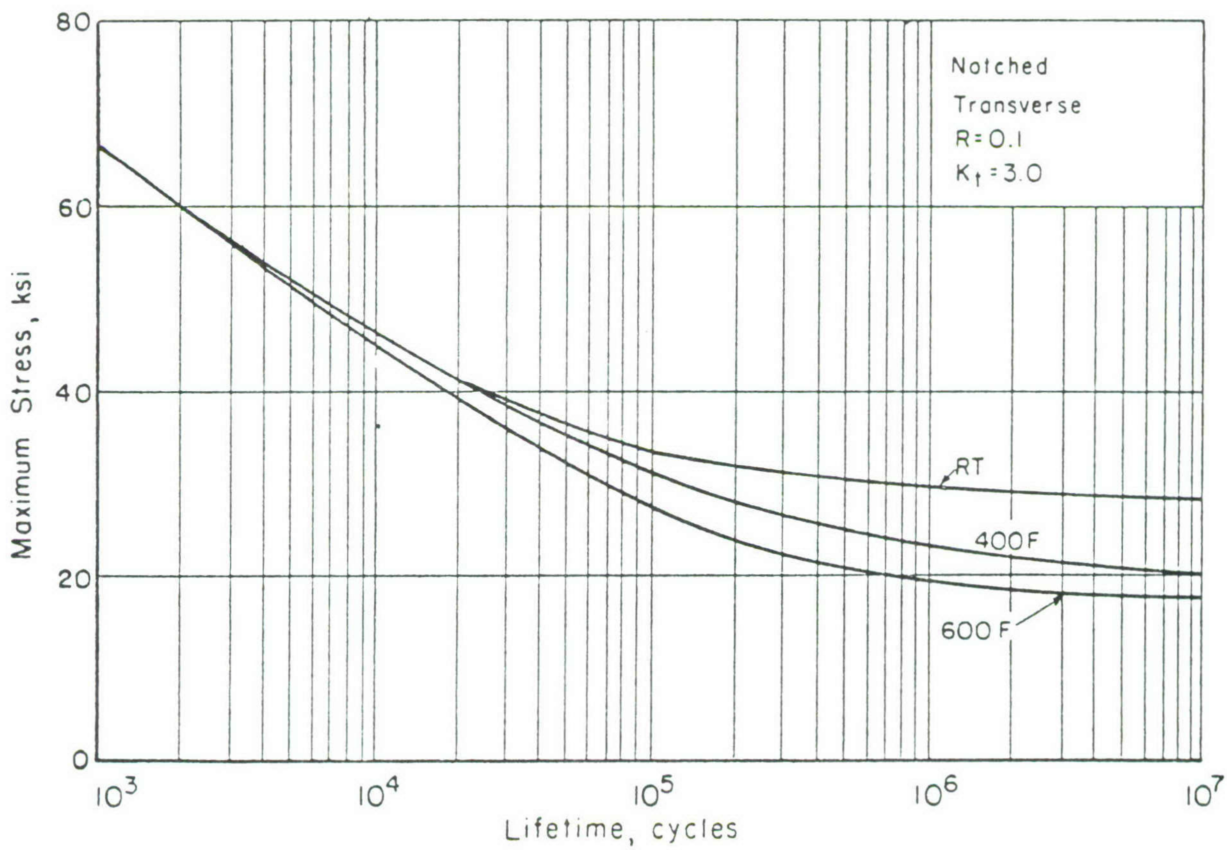


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED ($K_t = 3.0$) CROSS-ROLLED BERYLLIUM SHEET

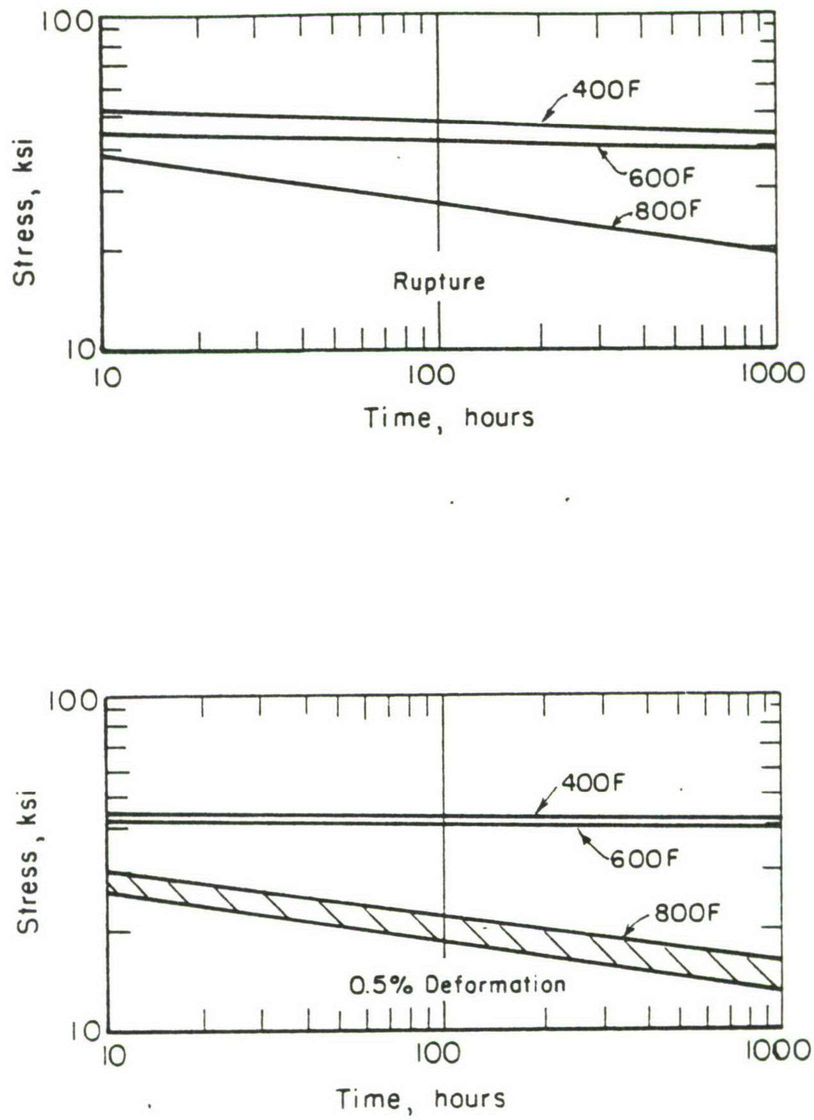


FIGURE 5. STRESS-RUPTURE AND 0.5-PERCENT DEFORMATION CURVES FOR CROSS-ROLLED BERYLLIUM SHEET

7039 Aluminum

Alloy 7039 is a recently developed heat-treatable, weldable aluminum alloy. The alloy was developed primarily for armor-plate applications; however, its high strength, weldability, formability, toughness, and corrosion resistance suggest it is suitable for cryogenic applications, missiles, and other structural applications where these properties are of importance.

Alloy 7039 is commercially available in plate, forgings, and extrusions. Sheet is available upon special inquiry.

7039 Aluminum Data[(a)]

Condition: -T6151
Thickness: 1.00-inch plate

Properties	Temperature, F -320	-105	RT	300	500
Tension					
F_{tu} (longitudinal), ksi	79.5	65.6	58.8	41.9	--
F_{tu} (transverse), ksi	78.3	65.1	58.2	41.7	--
F_{ty} (longitudinal), ksi	58.9	51.8	48.6	41.0	--
F_{ty} (transverse), ksi	58.1	51.3	47.9	40.4	--
e_t (longitudinal), percent in 2 in.	20.3	16.0	17.0	33.0	--
e_t (transverse), percent in 2 in.	18.0	17.0	16.0	31.0	--
RA (longitudinal), percent	26.9	31.7	38.8	62.2	--
RA (transverse), percent	24.9	30.3	35.8	55.8	--
E_t (longitudinal), 10^6 psi	11.7	11.0	10.2	9.5	--
E_t (transverse), 10^6 psi	11.8	11.3	10.3	9.5	--
Compression					
F_{cy} (longitudinal), ksi	56.9	50.4	47.5	41.4	--
F_{cy} (transverse), ksi	60.5	53.1	50.6	42.6	--
E_c (longitudinal), 10^6 psi	11.1	10.4	11.1	9.3	--
E_c (transverse), 10^6 psi	12.1	10.5	10.3	9.9	--
Shear[(d)]					
F_{su} (longitudinal), ksi	U	U	33.7	U	--
F_{su} (transverse), ksi	U	U	31.9	U	--
Impact					
Charpy V-notch					
Longitudinal, ft-lb	9.2	U[(b)]	12.7	16.2	--
Transverse, ft-lb	6.0	U	9.0	10.8	--

Properties	Temperature, F -320	-105	RT	300	500
Fracture Toughness(c)					
K_{IC}, ksi $\sqrt{inch}$	U	U	48.2	(c)	--
Axial Fatigue (transverse)					
Unnotched, R = 0.1(e)					
10^3 cycles, ksi	90.0	U	61.0	52.0	--
10^5 cycles, ksi	71.0	U	48.0	46.0	--
10^7 cycles, ksi	56.0	U	38.0	38.0	--
Notched, K_t = 3.0(e), R = 0.1					
10^3 cycles, ksi	73.0	U	58.0	53.0	--
10^5 cycles, ksi	34.0	U	17.5	20.0	--
10^7 cycles, ksi	18.0	U	10.0	11.0	--
Creep (transverse)					
0.5% elongation, 100 hours, ksi	--	--	NA(b)	24.0	3.8
0.5% elongation, 1000 hours, ksi	--	--	NA	19.0	2.7
Stress Rupture (transverse)					
Rupture, 100 hours, ksi	--	--	NA	28.0	5.4
Rupture, 1000 hours, ksi	--	--	NA	21.0	3.7
Stress Corrosion					
80% F_{ty}, 1000 hours max.	--	--	No cracks(f)	U	U
Coefficient of Thermal Expansion(g)					
68 to 212 F	13.0×10^6 in./in./F				
Density(g)	0.0988 lb/in.^{3}				

(a) Data are averages of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, stress-rupture values are from data curves generated from the results of a greater number of tests.
(b) U = unavailable; NA = not applicable.
(c) Fatigue-cracked single-edge-notched specimen (1 x 2 x 18 inch) tested in bending under 4-point loading. No pop-in detected at 300 F.
(d) Double shear (1/4-inch pin).

(e) "R" represents the algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Alternate immersion, 3-1/2 percent NaCl. Three-point loading bend test.

(g) Values from "Aluminum Alloy 7039", Kaiser Aluminum Brochure (June, 1965).

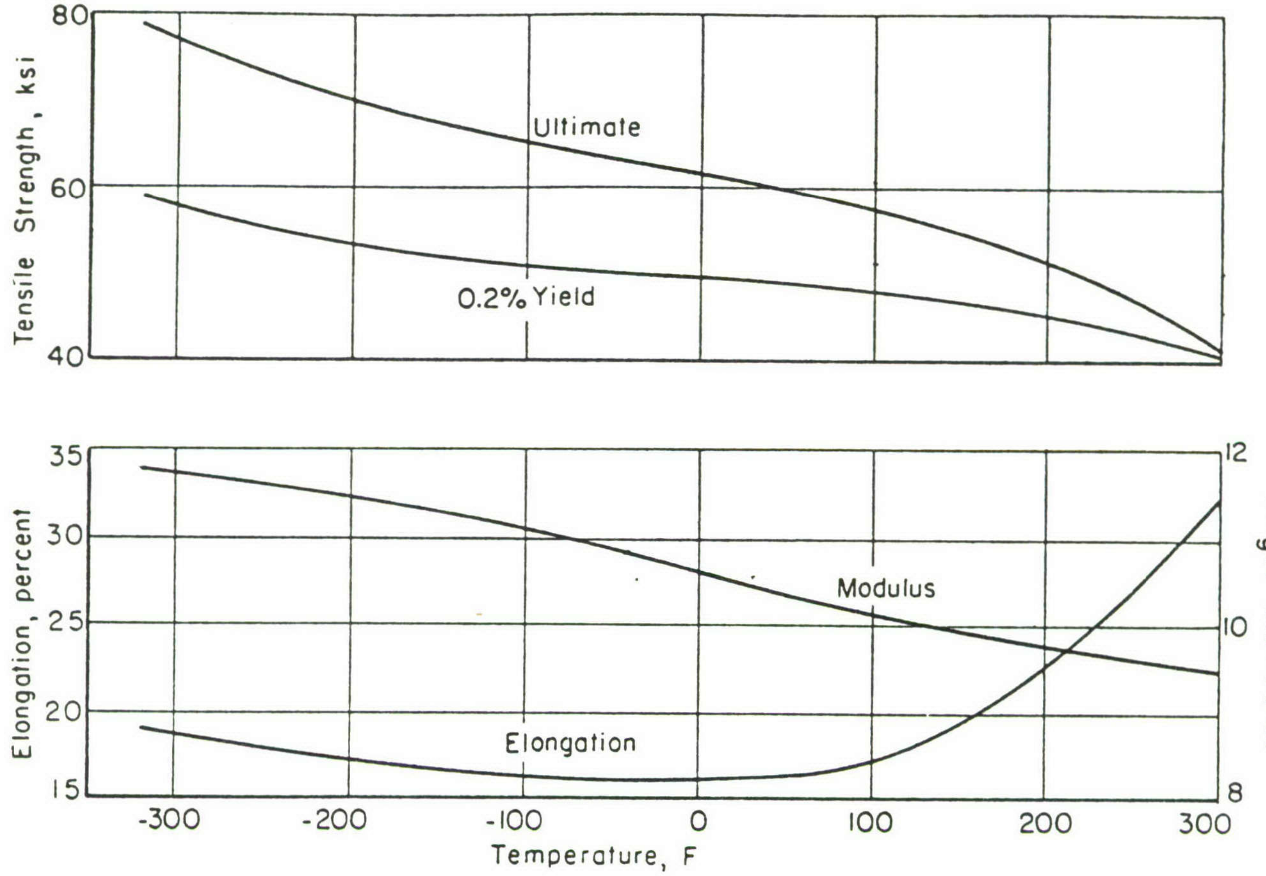


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7039-T6151 ALUMINUM ALLOY PLATE

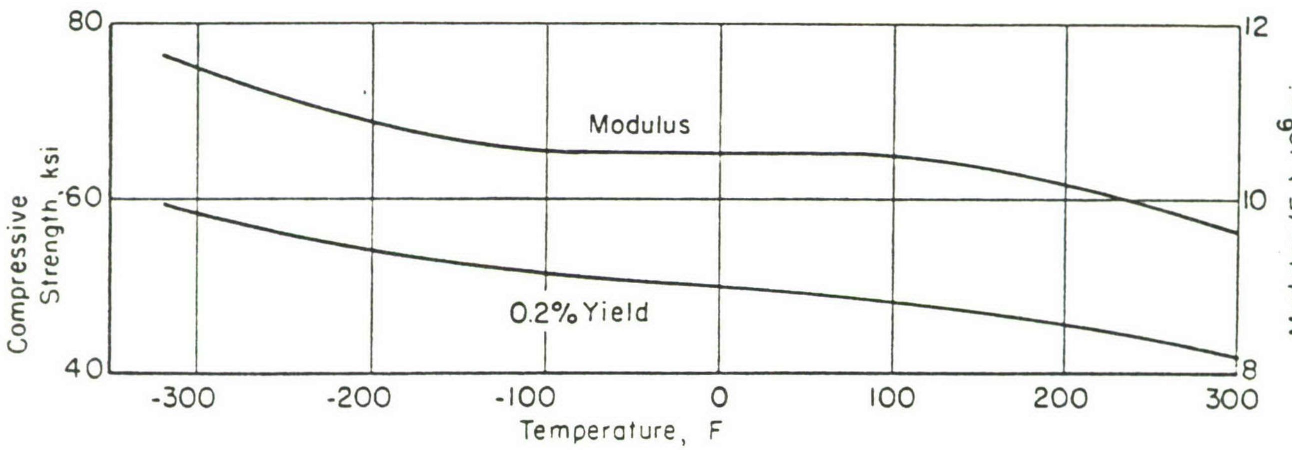


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 7039-T6151 ALUMINUM ALLOY PLATE

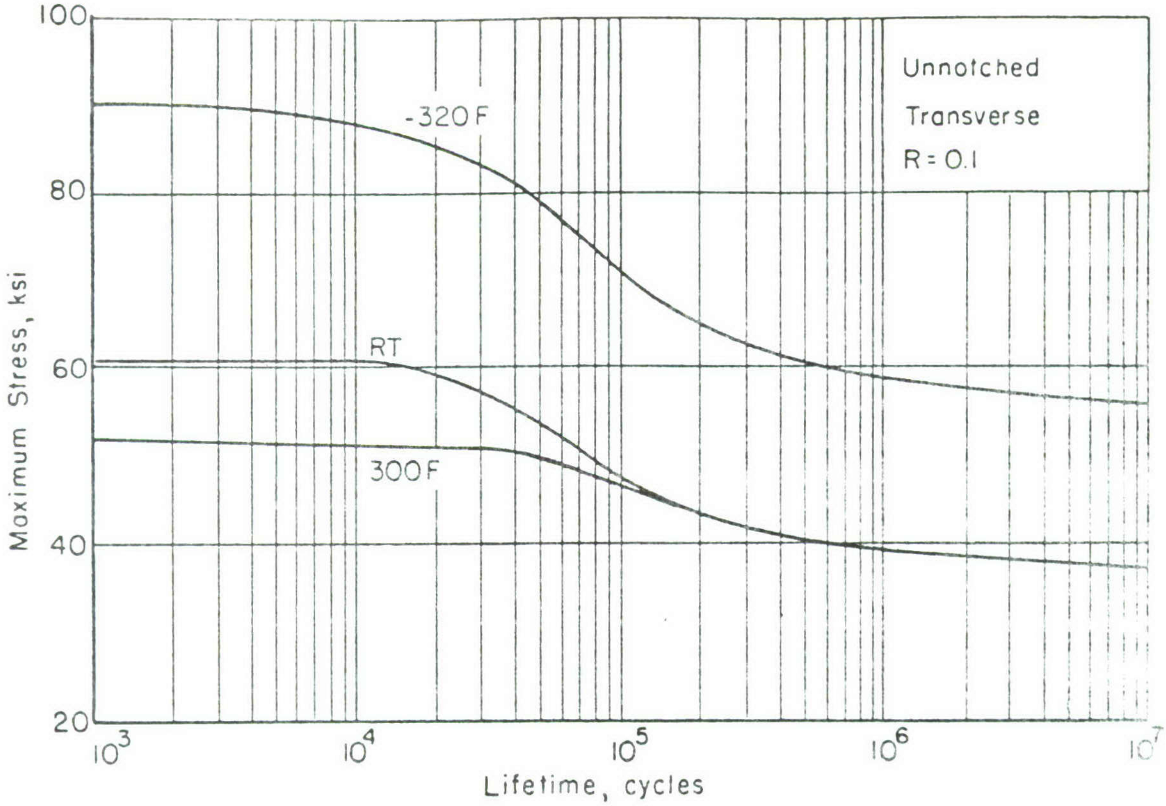


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 7039-T6151 ALUMINUM ALLOY PLATE

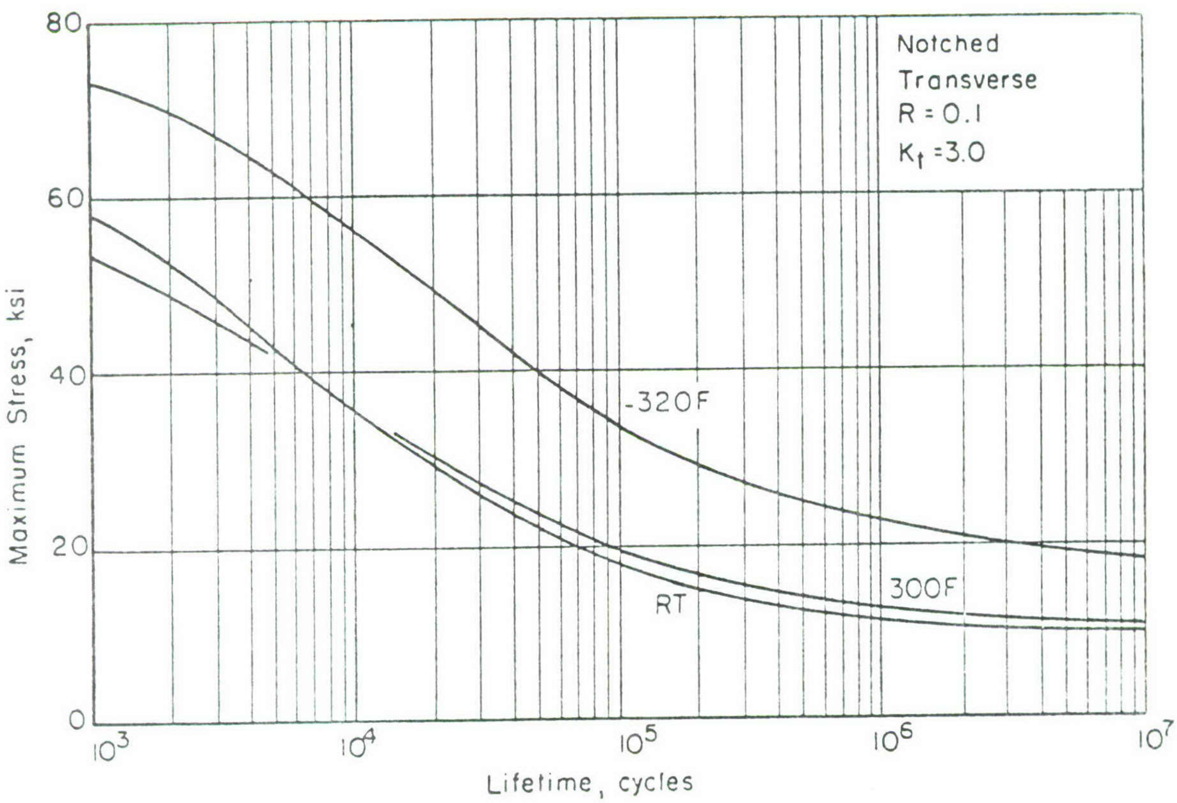


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 7039-T6151 ALUMINUM ALLOY PLATE

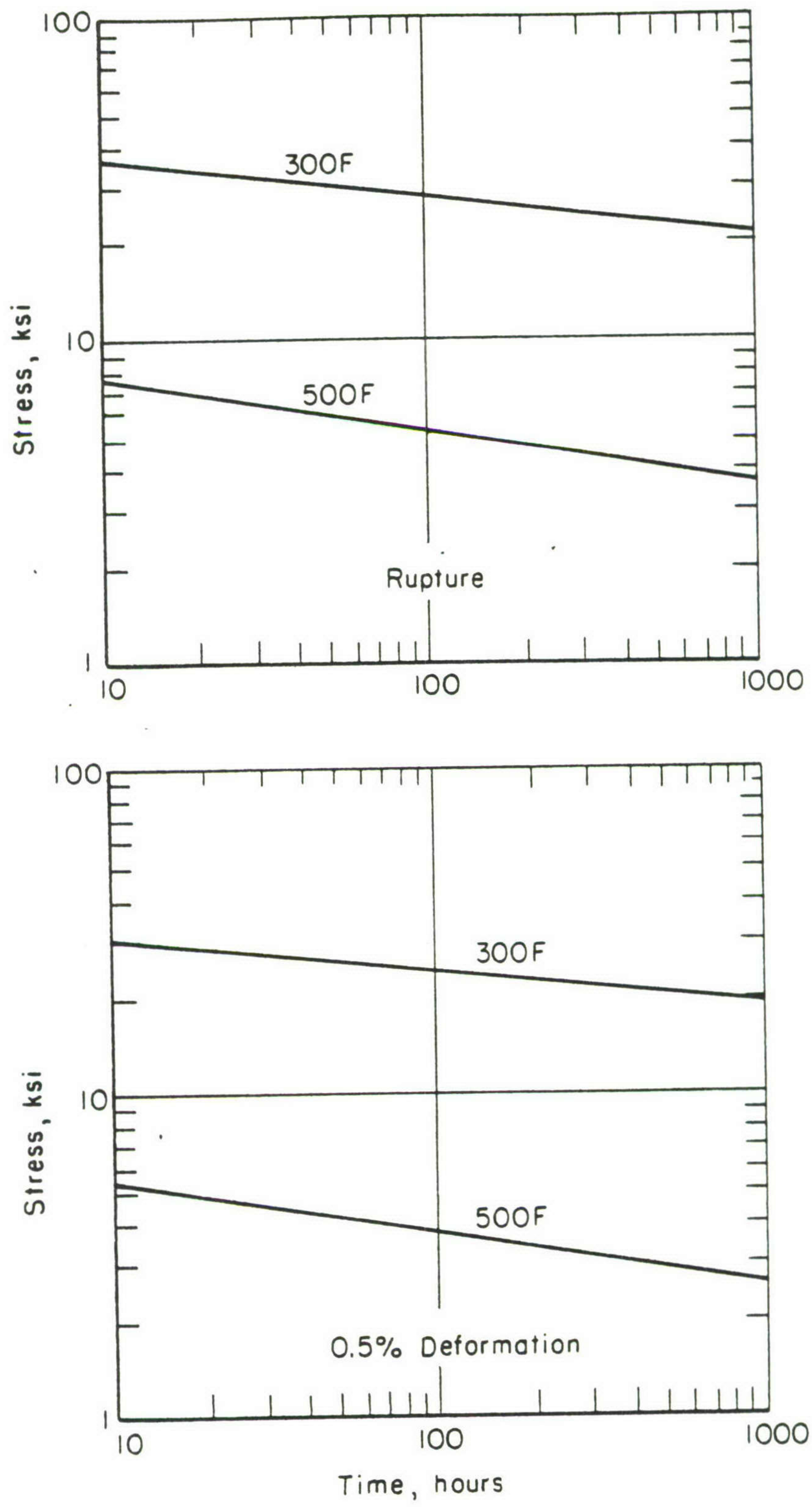


FIGURE 5. STRESS-RUPTURE AND 0.5-PERCENT DEFORMATION CURVES FOR 7039-T6151 ALUMINUM ALLOY PLATE

2021 Aluminum

2021 is a newly developed, weldable, high-strength aluminum alloy. It has been developed as a candidate material for cryogenic structure and tankage applications with particular reference to the requirements of liquid propellant space boosters. Preliminary studies have shown that this alloy is suitable for fabrication in plate thicknesses and compares favorably with other high-strength aluminum alloys in resistance to corrosion and stress-corrosion cracking.

2021 is not yet commercially available.

This is no longer an active alloy.

2021 Aluminum Data[a]

Condition: -T8E31
Thickness: 0.250-inch plate

Properties	Temperature, F				
	-320	-105	RT	300	500
Tension					
F_{tu} (longitudinal), ksi	85.4	74.3	69.7	55.9	
F_{tu} (transverse), ksi	88.6	77.1	73.5	56.8	
F_{ty} (longitudinal), ksi	71.0	60.5	58.2	51.6	
F_{ty} (transverse), ksi	71.2	59.8	59.5	51.5	
e_t (longitudinal), percent in 2 in.	13.8	17.2	14.8	13.5	
e_t (transverse), percent in 2 in.	11.0	11.5	10.8	12.0	
E_t (longitudinal), 10^6 psi	11.6	11.3	10.1	9.0	
E_t (transverse), 10^6 psi	11.7	10.8	10.4	9.5	
Compression					
F_{cy} (longitudinal), ksi	74.2	63.1	62.3	56.4	
F_{cy} (transverse), ksi	77.3	65.4	63.7	57.6	
E_c (longitudinal), 10^6 psi	12.3	11.7	11.0	10.0	
E_c (transverse), psi x 10^6	12.2	11.6	11.2	10.2	
Shear[b]					
F_{su} (longitudinal), ksi	U[c]	U	45.0	U	
F_{su} (transverse), ksi	U	U	46.8	U	
Impact					
Charpy V-notch	U	U	U	U	
Fracture Toughness					
K_{IC}, ksi $\sqrt{\text{inch}}$	U	U	no pop-in[d]	U	

Properties	Temperature, F -320	-105	RT	300	500
Axial Fatigue (transverse)[e]					
Unnotched, R = 0.1					
10^3 cycles, ksi	94.0	U	80.0	68.0	
10^5 cycles, ksi	80.0	U	60.0	48.0	
10^7 cycles, ksi	59.0	U	39.0	20.0	
Notched, K_t = 3.0, R = 0.1					
10^3 cycles, ksi	75.0	U	57.0	46.0	
10^5 cycles, ksi	33.0	U	25.0	19.0	
10^7 cycles, ksi	20.0	U	15.0	11.0	
Creep (transverse)					
0.2% elongation, 100 hours, ksi			NA[c]	33.0	7.7
0.2% elongation, 1000 hours, ksi			NA	27.0	5.0
Stress Rupture (transverse)					
Rupture, 100 hours, ksi			NA	36.0	10.4
Rupture, 1000 hours, ksi			NA	29.0	5.5
Stress Corrosion					
80% F_{ty}, 1000 hours max.			Failed[f]	U	U
Coefficient of Thermal Expansion					
68 to 212 F	13.2×10^{-6} in./in./F				
Density	0.101 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.
(b) Single shear sheet type specimen, full thickness.
(c) U = unavailable; NA = not applicable.
(d) Fatigue-cracked, single-edge-notched specimen (1/4 x 3 x 12 inches) tested in tension. No pop-in detected.
(e) "R" represents the algebraic ratio of the minimum stress to the maximum stress in 1 cycle; that is, R = S_{min}/S_{max}. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.
(f) Three-point bend test. Alternate immersion 3-1/2% NaCl. All specimens failed. First signs of cracking appeared within 24 hours. Elapsed time between first signs of cracking and failure was 4 days.

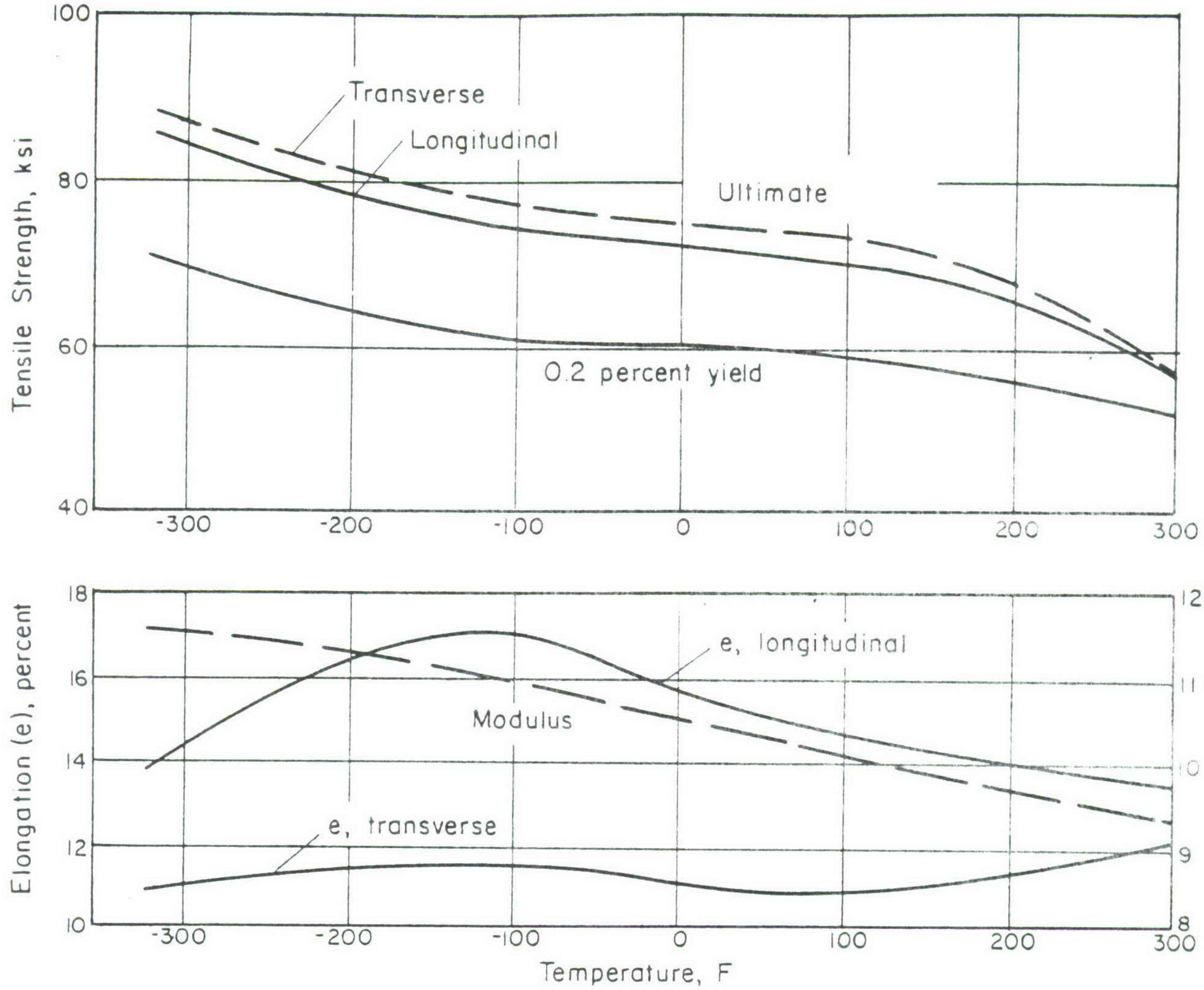


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 2021-T8E31 ALUMINUM ALLOY PLATE

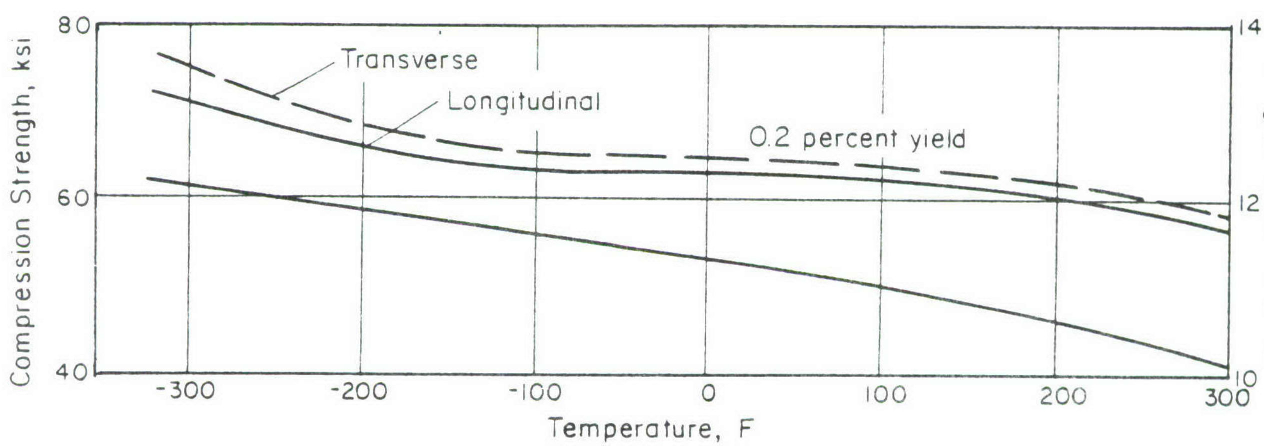


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 2021-T8E31 ALUMINUM ALLOY SHEET

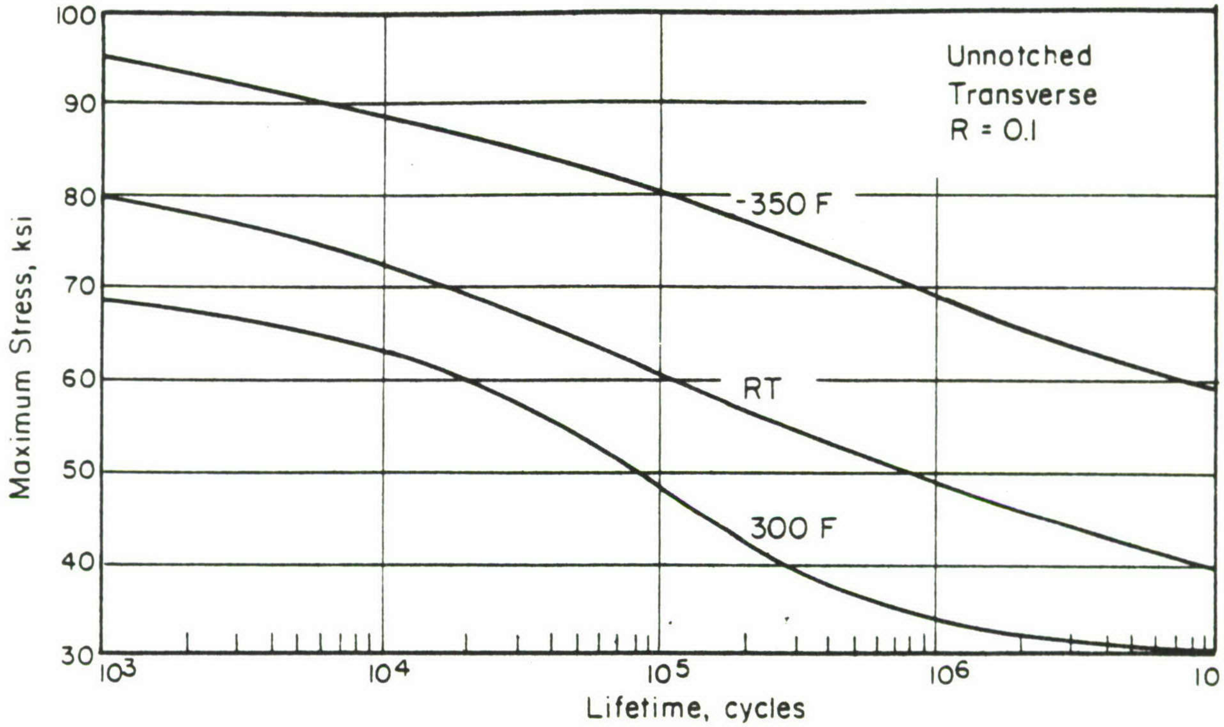


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 2021-T8E31 AT THREE TEMPERATURES

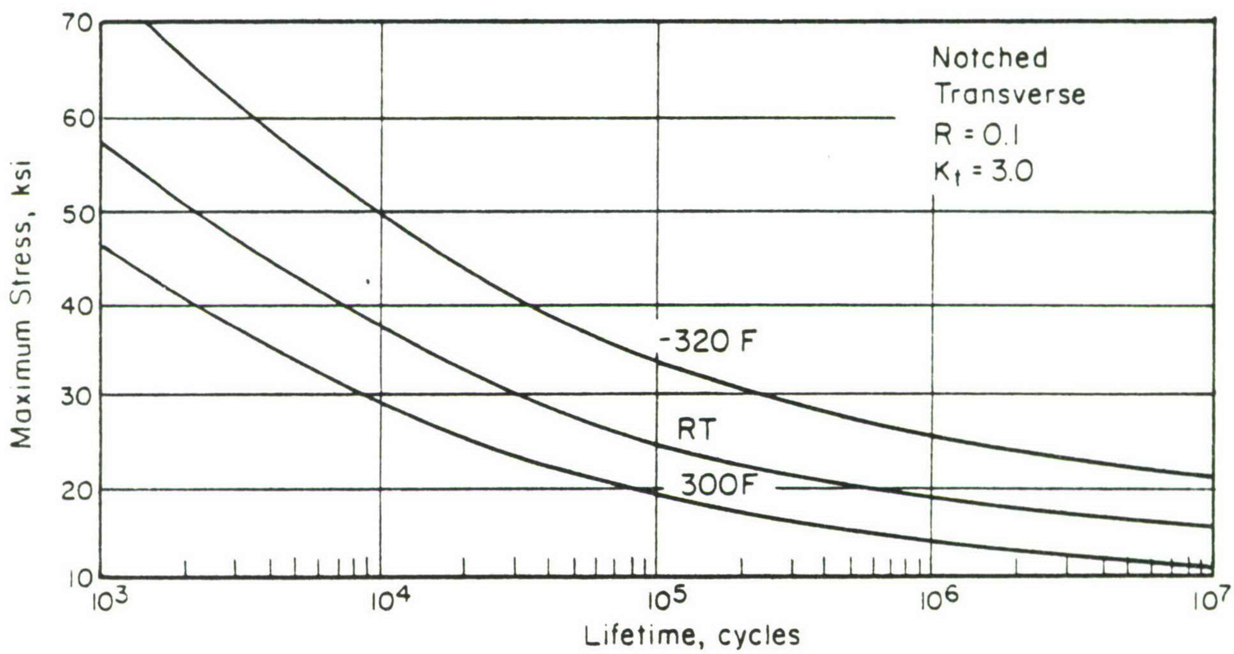
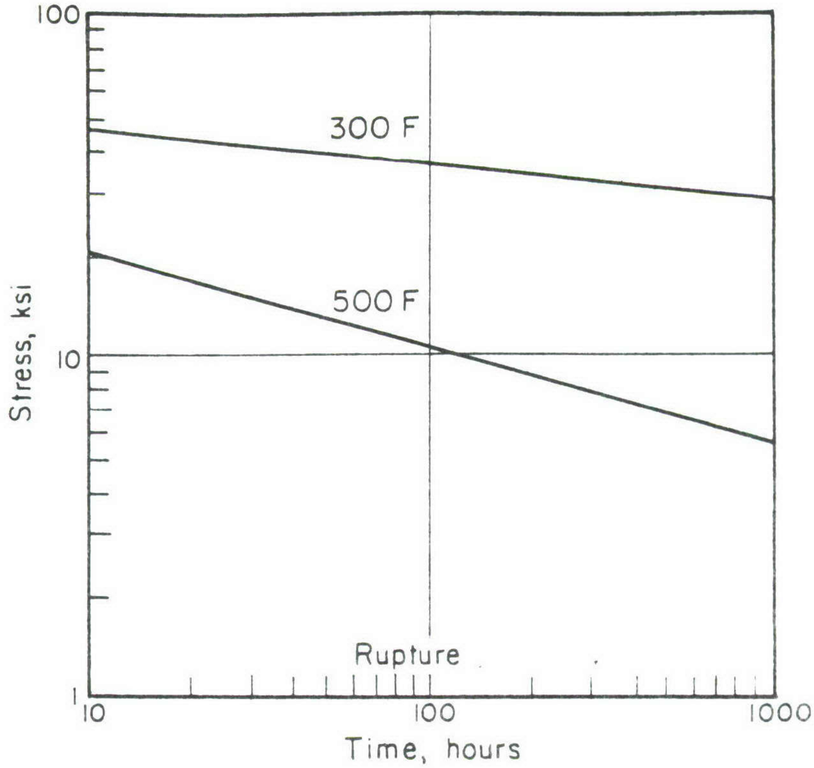


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 2021-T8E31 AT THREE TEMPERATURES



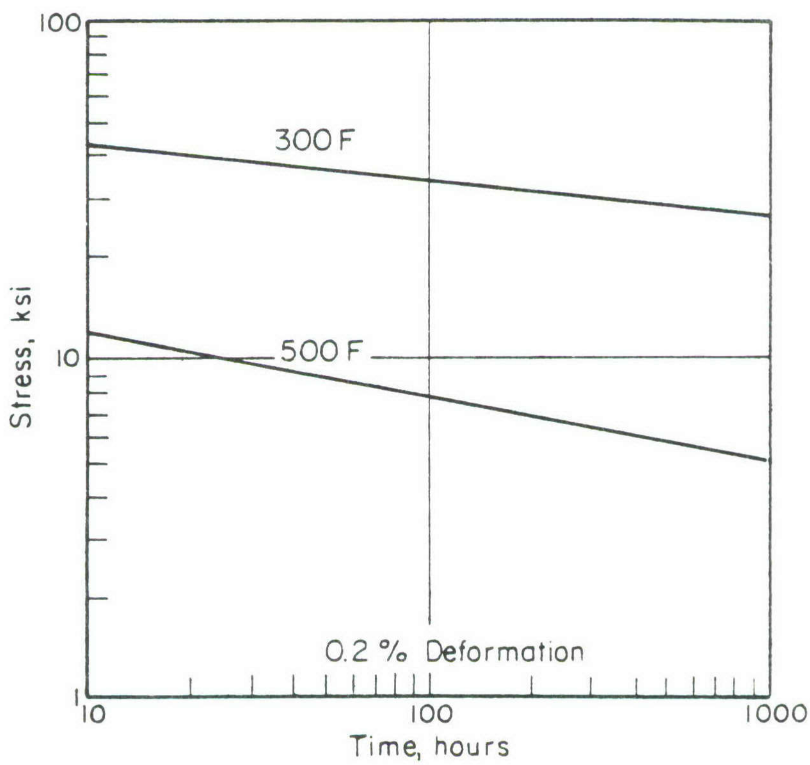


FIGURE 5. STRESS-RUPTURE AND 0.2-PERCENT DEFORMATION CURVES FOR 2021-T8E31 AT TWO TEMPERATURES

7007-T6E136

7007 has been developed over the past 3 years by ALCOA under Contract NAS 8-5452. It shows promise as a tough, readily weldable aluminum alloy and could possibly replace the alloy 2219, which is currently used in space vehicles. Further development work is planned, particularly concerned with the effort to improve the weld properties of this alloy.

The -T6E136 treatment was selected to provide the optimum combination of strength and notch toughness.

The nominal composition of 7007 is as follows: 0.10 Cu, 0.2 Mn, 1.8 Mg, 0.12 Cr, 6.5 Zn, 0.04 Ti, 0.12 Zr, and 0.40 max Si + Fe.

This is no longer an active alloy.

7007 Data(a)

Condition: -T6E136
Thickness: 0.250-Inch Plate

Properties	Temperature, F			
	-320	-105	RT	300
Tension				
F_{tu} (longitudinal), ksi	98.1	83.3	72.9	51.2
F_{tu} (transverse), ksi	90.2	78.4	69.1	50.1
F_{ty} (longitudinal), ksi	83.8	73.2	68.8	49.4
F_{ty} (transverse), ksi	77.5	70.1	65.2	49.5
e_t (longitudinal), percent in 2 in.	16.0	13.7	14.0	20.2
e_t (transverse), percent in 2 in.	13.8	13.2	15.8	20.7
E_t (longitudinal), 10^6 psi	10.8	10.7	10.1	9.7
E_t (transverse), 10^6 psi	10.8	11.1	10.0	9.3
Compression				
F_{cy} (longitudinal), ksi	85.0	76.0	69.4	54.0
F_{cy} (transverse), ksi	85.5	76.4	69.7	55.8
E_c (longitudinal), 10^6 psi	12.1	11.7	10.8	10.6
E_c (transverse), 10^6 psi	12.2	11.9	11.0	10.6
Shear(b)				
F_{su} (longitudinal), ksi	U(c)	U	46.2	U
F_{su} (transverse), ksi	U	U	44.7	U
Impact (Charpy V-notch), ft-lb	U	3.6	4.2	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	U	U	No pop-in(d)	U

Properties	Temperature, F -320	-105	RT	300
Axial Fatigue (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	95	U	73	59
10^5 cycles, ksi	82	U	53	45
10^7 cycles, ksi	72	U	39	27
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	65	U	52	50
10^5 cycles, ksi	31	U	20	17
10^7 cycles, ksi	20	U	16	11

Properties	Temperature, F RT	300	500
Creep (transverse)			
0.2% plastic deformation 100 hr, ksi	NA[c]	18.2	2.9
0.2% plastic deformation 1000 hr, ksi	NA	11.3	1.9
Stress Rupture (transverse)			
Rupture 100 hr, ksi	NA	27.5	5.3
Rupture 1000 hr, ksi	NA	19.6	3.6
Stress Corrosion			
80% F_{ty}, 1000 hr max.	No cracks[f]	U	U

Coefficient of Thermal Expansion[g]

12.2×10^{-6} in./in./F (68-212 F)
13.8×10^{-6} in./in /F (68-392 F)

Density[g] 0.101 lb/in.^{3}

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using the results of a greater number of tests.

(b) Single shear sheet type specimens, full thickness.

(c) U = unavailable; NA = not applicable.

(d) Fatigue-cracked single-edge-notched specimens (1/4 x 3 x 12 in.) tested in tension. No pop-in detected. Load-strain curves were analyzed by the secant offset method as outlined in ASTM 410 and proved to be invalid tests.

(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion 3-1/2 percent NaCl. No cracks appeared.

(g) Values from Reference (1).

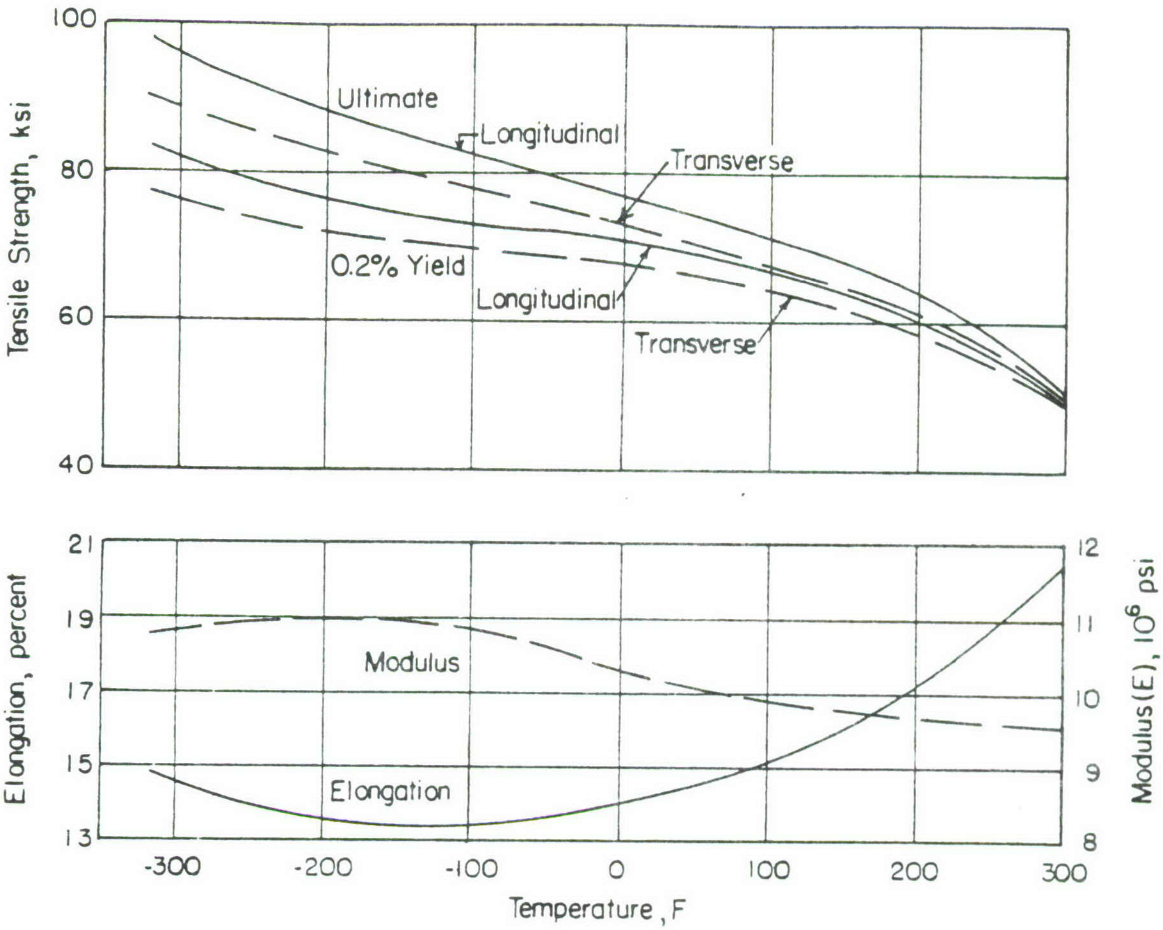


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7007-T6E136 ALUMINUM ALLOY PLATE

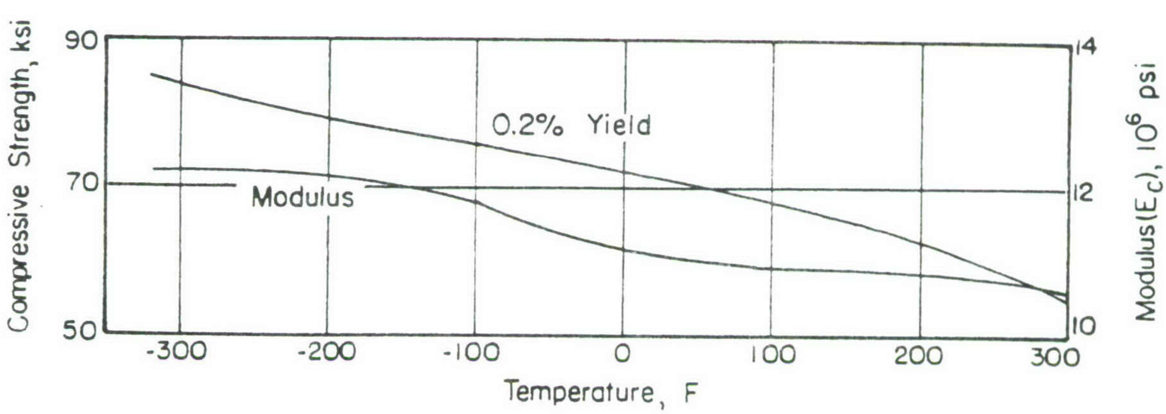


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7007-T6E136 ALUMINUM ALLOY PLATE

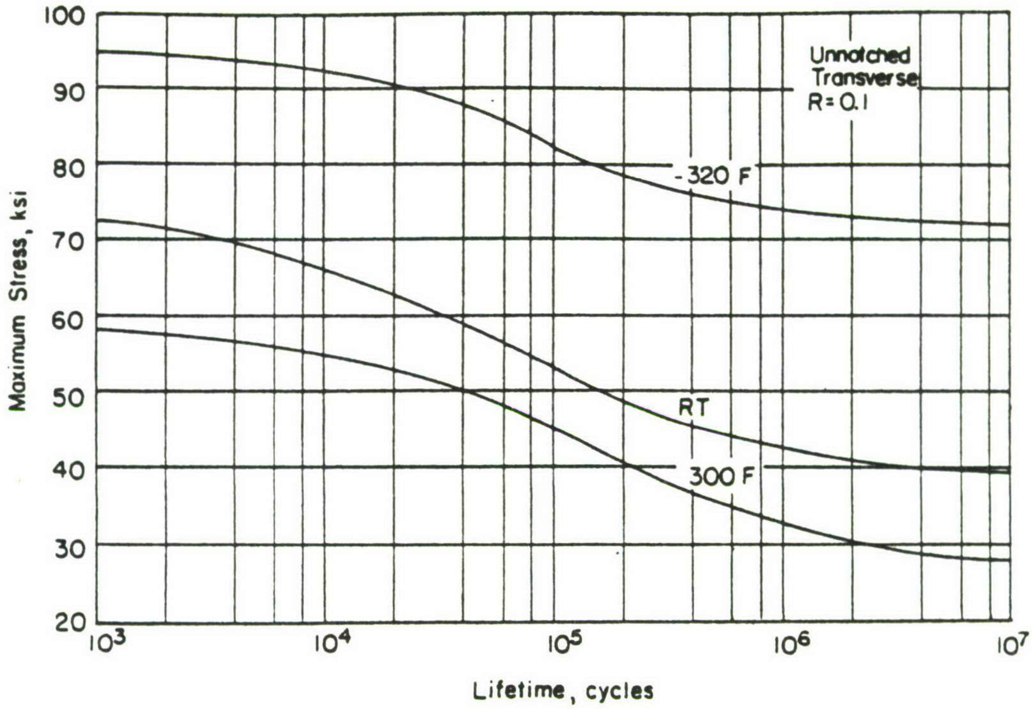


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 7007-T6E136 ALUMINUM PLATE AT THREE TEMPERATURES

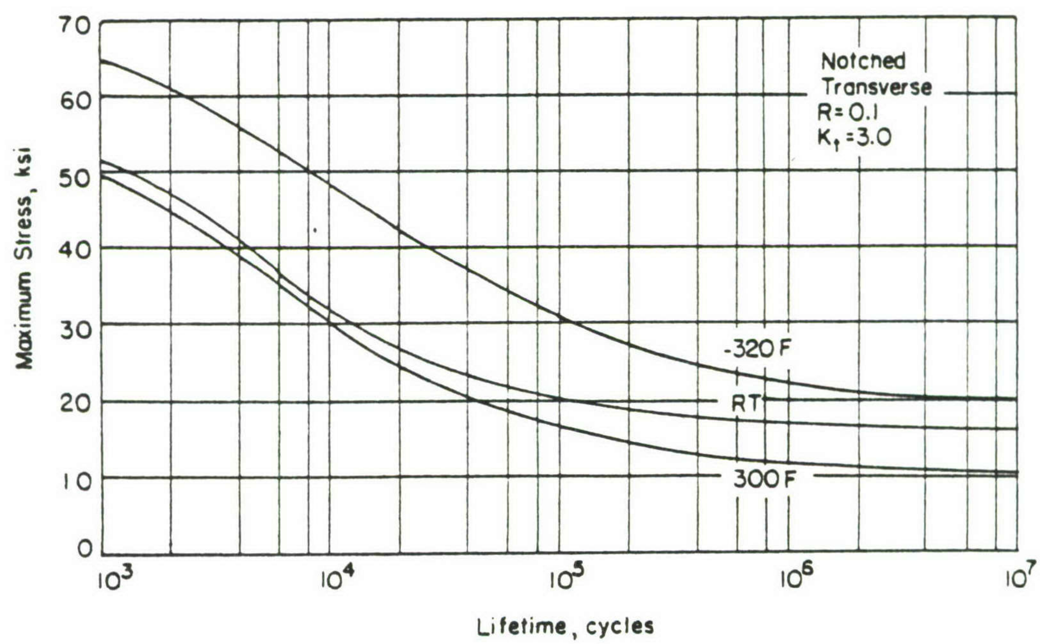


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 7007-T6E136 ALUMINUM PLATE AT THREE TEMPERATURES

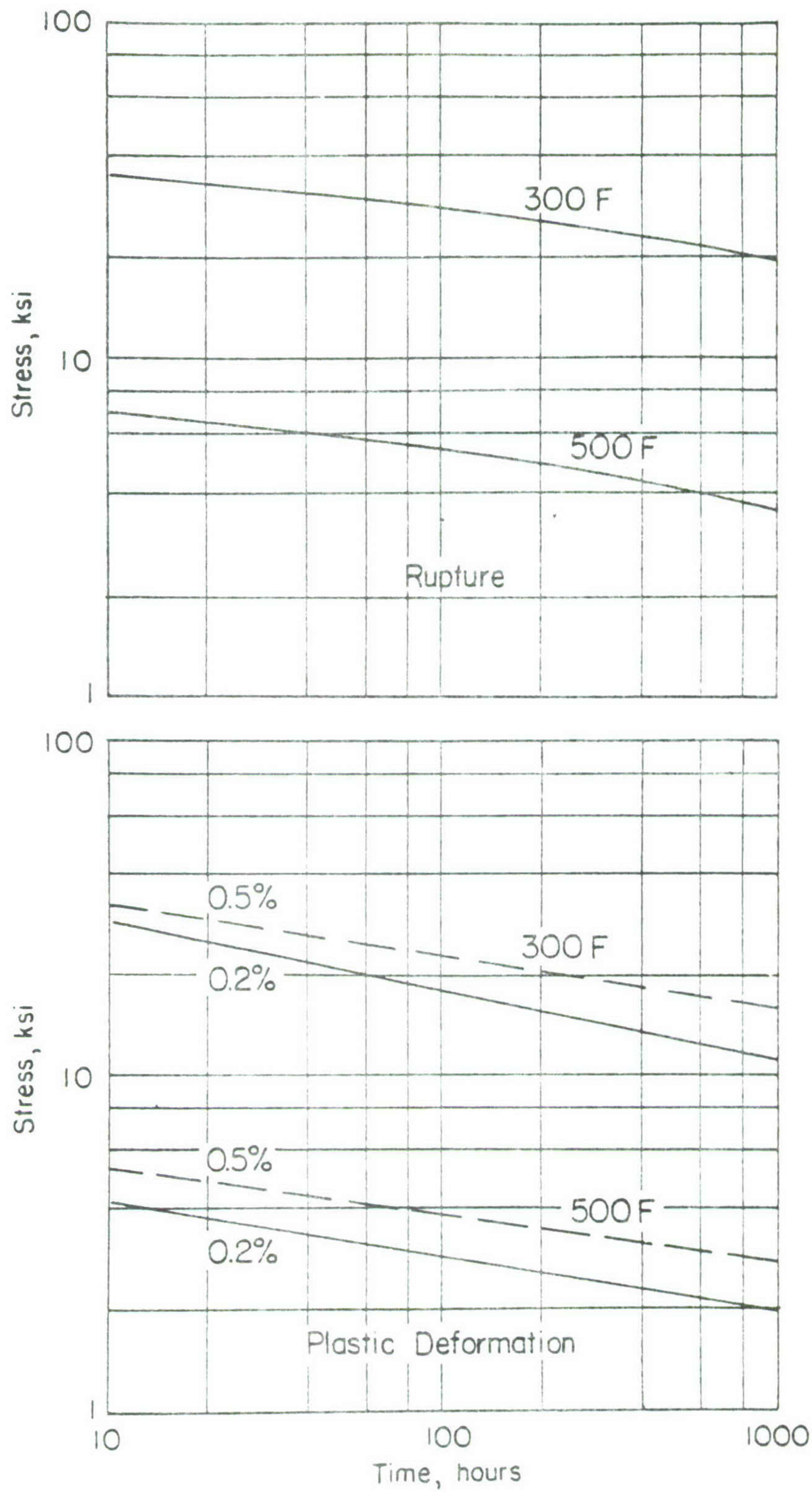


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7007-T6E136 ALUMINUM ALLOY PLATE

HM21A

This alloy is one of a fairly recently developed series of heat-treatable magnesium alloys containing thorium and manganese as hardeners. It is intended primarily for service from 500 to about 800 F, where it is superior from a strength standpoint to the other magnesium alloys available in sheet and plate form.

This alloy can be welded and need not be stress relieved to prevent stress corrosion. It should be noted that HM21A in the -T81 temper is strain-rate sensitive.

The nominal composition of HM21A is as follows: 2.0 thorium, 0.80 manganese, other impurities to total not more than 0.30.

HM21A Data[a]

Condition: T81
Thickness: 0.160-Inch Sheet

Properties	Temperature, F RT	300	500	700
Tension				
F_{tu} (longitudinal), ksi	35.1	26.5	20.9	11.1
F_{tu} (transverse), ksi	36.5	26.1	21.0	12.9
F_{ty} (longitudinal), ksi	28.8	24.2	19.5	10.2
F_{ty} (transverse), ksi	27.5	22.8	18.9	11.6
e_t (longitudinal), percent in 2 in.	6.2	13.0	12.0	42.2
e_t (transverse), percent in 2 in.	15.8	21.7	13.3	34.2
E_t (longitudinal), 10^6 psi	5.83	5.76	5.38	4.10
E_t (transverse), 10^6 psi	6.05	5.84	5.26	4.58
Compression				
F_{cy} (longitudinal), ksi	23.2	21.7	19.0	10.8
F_{cy} (transverse), ksi	23.3	21.2	19.3	12.9
E_c (longitudinal), 10^6 psi	6.43	6.12	5.97	4.91
E_c (transverse), 10^6 psi	6.67	6.20	5.91	5.04
Shear[b]				
F_{su} (longitudinal), ksi	27.2	U	U	U
F_{su} (tranverse), ksi	27.5	U	U	U
Impact (V-notch Charpy)	U[c]	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	U[d]	U	U	U

Properties	Temperature, F RT	300	500	700
Axial Fatigue (transverse)(e)				
Unnotched, R = 0.1				
10^3 cycles, ksi	32.2	32.2	27.0	U
10^5 cycles, ksi	27.2	23.7	23.0	U
10^7 cycles, ksi	18.9	14.4	13.5	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	25.6	25.6	22.5	U
10^5 cycles, ksi	12.5	11.2	11.2	U
10^7 cycles, ksi	9.3	6.0	4.5	U
Creep (transverse)				
0.2% plastic deformation 100 hr, ksi	NA	21.4	12.8	3.1
0.2% plastic deformation 1000 hr, ksi	NA	20.8	11.0	1.8
Stress Rupture (transverse)				
Rupture 100 hr, ksi	NA	22.9	15.6	3.9
Rupture 1000 hr, ksi	NA	22.4	13.5	2.5
Stress Corrosion				
80% F_{ty}, 100 hr max	No cracks(f)	U	U	U
Coefficient of Thermal Expansion(g)				
12.2×10^{-6} in./in./F (68-212 F)				
13.8×10^{-6} in./in./F (68-392 F)				
Density(g) 0.064 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Single-shear sheet type specimen, full thickness.

(c) U, unavailable; NA, not applicable.

(d) Single-edge-notched (3 x 12 in.) tension specimen. No pop-in detected. Load-strain curves were analyzed by the secant modulus method in ASTM STP 410 and proved to be invalid K_{Ic} tests.

(e) "R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, R = S_{min}/S_{max}. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl. No cracks appeared.

(g) Values from References (1) and (2).

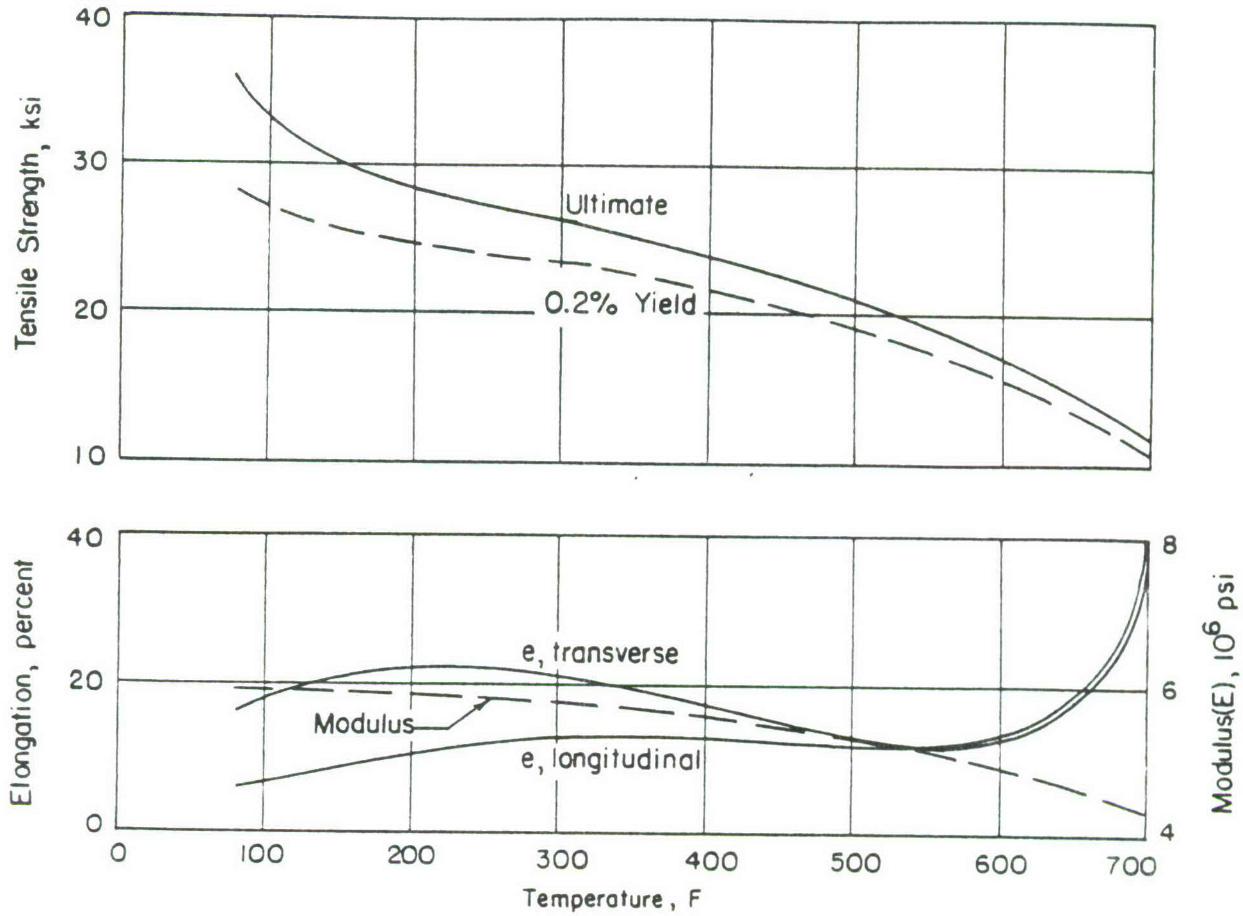


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HM21A-T81 MAGNESIUM SHEET

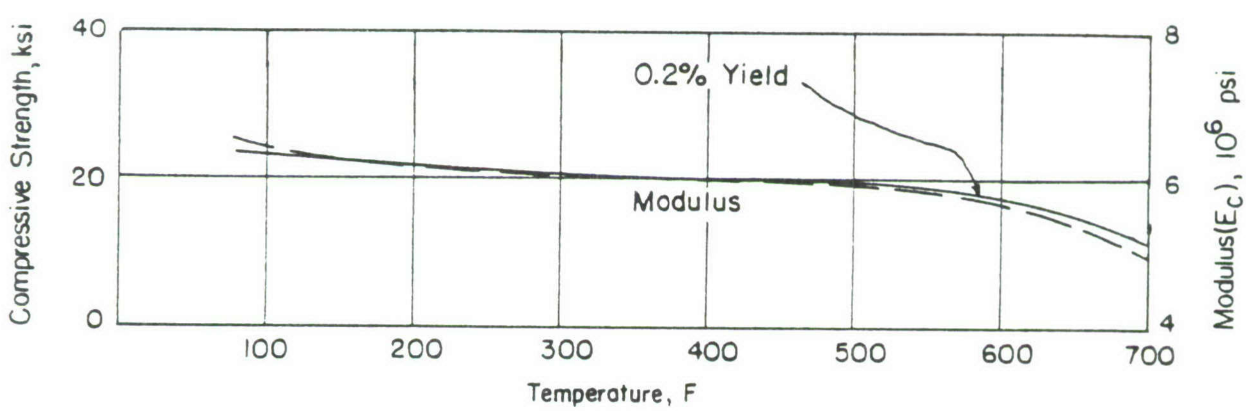


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF HM21A-T81 MAGNESIUM SHEET

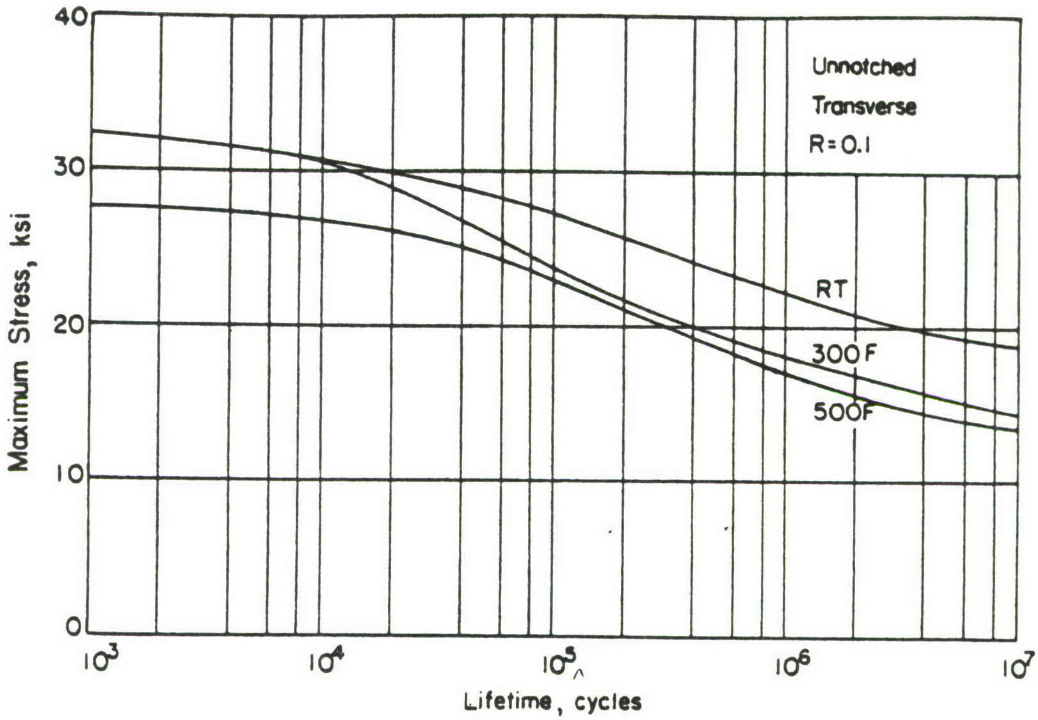


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR HM21A-T81 MAGNESIUM SHEET

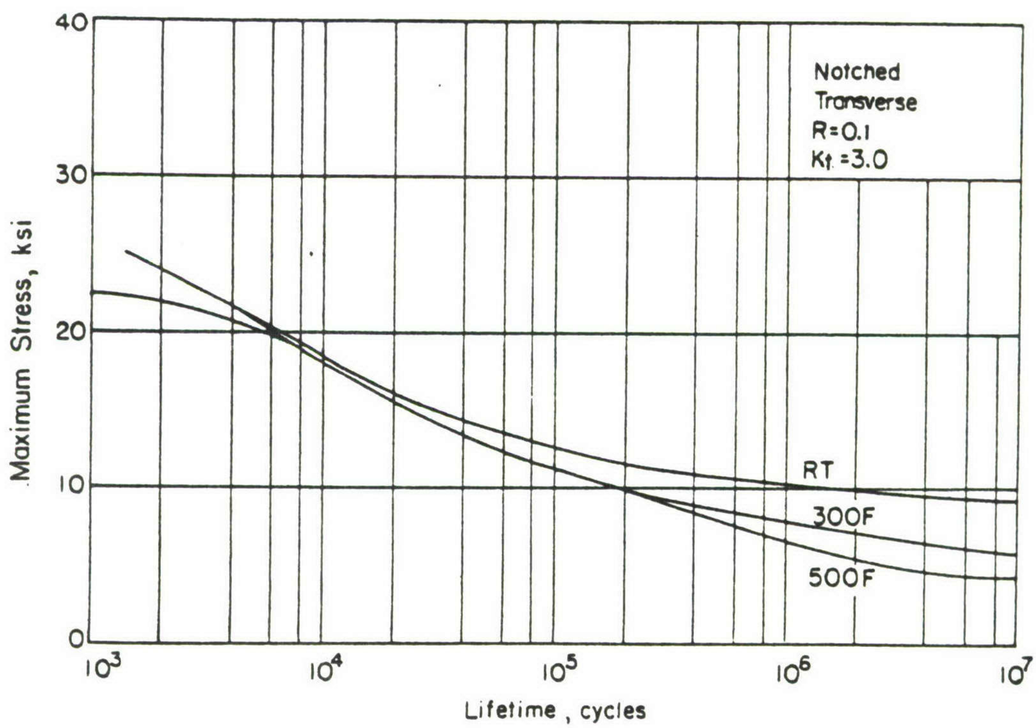


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) HM21A-T81 MAGNESIUM SHEET

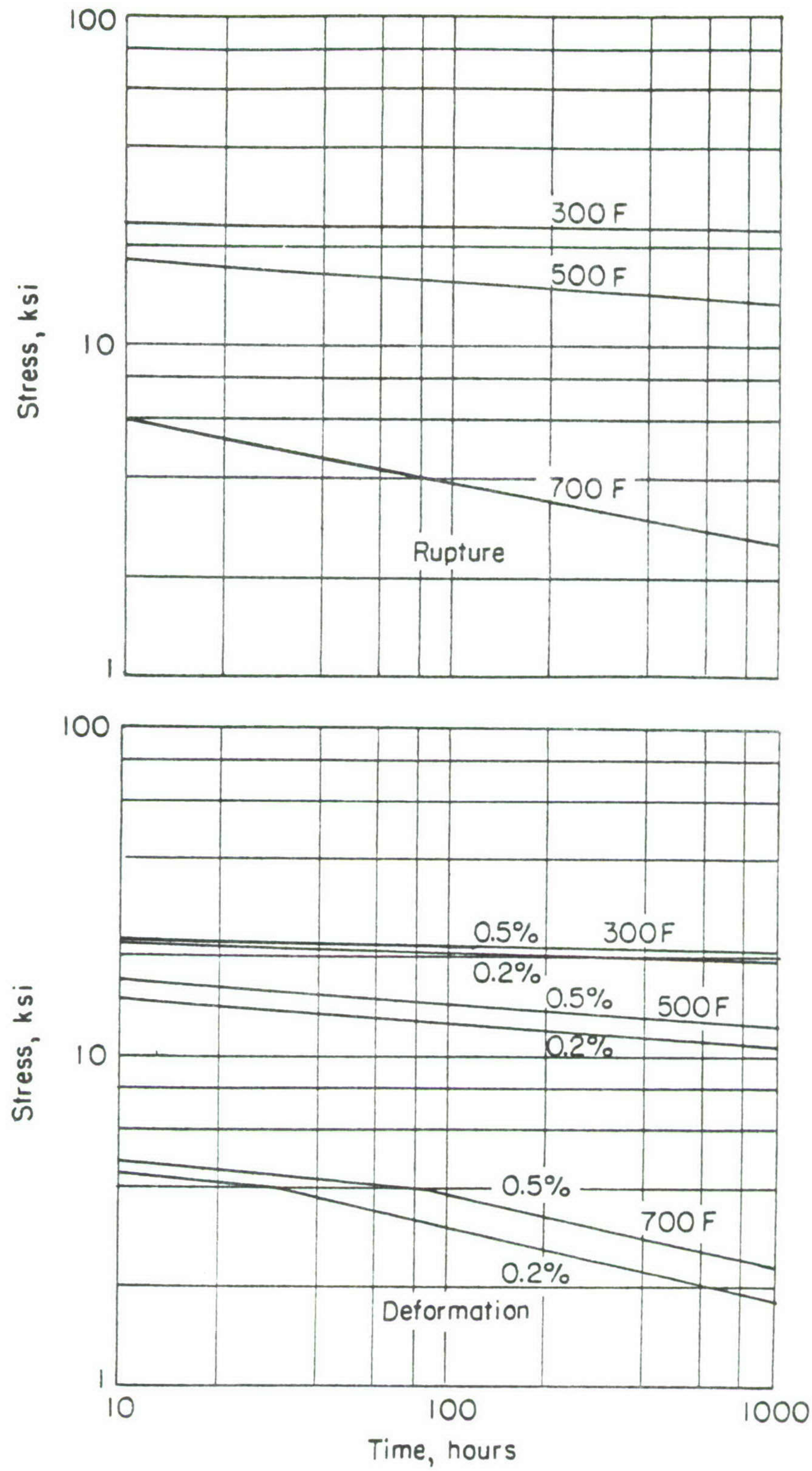


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR HM21A-T81 MAGNESIUM SHEET AT THREE TEMPERATURES

AFC-260

AFC-260 is a semiaustentic precipitation-hardenable stainless steel recently developed by the Crucible Steel Company under Air Force Contract AF 33(615)-2201. The composition is balanced so that it can be heat treated to an austenitic structure suitable for cold or warm deformation. With additional thermal treatments, AFC-260 can be transformed to martensite and then age hardened to high strength levels.

Preliminary data show that the new AFC-260 retains its strength well upon prolonged exposure to elevated temperatures, that its oxidation resistance is comparable to that of currently available semiaustenitic stainless steels, and that it can be satisfactorily welded with the resulting welds exhibiting a high degree of strength efficiency.

The nominal composition of AFC-260 is as follows:

C	Cr	Ni	Mo	Co	Cb	N	Fe
0.07	15.5	1.85	4.5	13.0	0.15	0.03	Bal.

The heat treatment (designated 19RA by Crucible) used for this test program is as follows:

Solution anneal at 1900 F and air cool,
Refrigerate at -100 F for 8 hours,
Age at 1000 F for 2+2 hours.

AFC-260 is presently available in sheet and bar form.

AFC-260 Data[a]

Condition: Aged
Thickness: 0.060-Inch Sheet

Properties	Temperature, F RT	500	700	900
Tension				
F_{tu} (longitudinal), ksi	254.0	220.0	215.0	201.0
F_{tu} (transverse), ksi	253.0	220.0	215.7	203.3
F_{ty} (longitudinal), ksi	205.7	176.7	161.3	140.0
F_{ty} (transverse), ksi	201.3	176.7	160.0	145.3
e_t (longitudinal), percent in 2 in.	10.3	6.0	5.7	7.8
e_t (transverse), percent in 2 in.	10.3	6.0	5.8	8.2
E_t (longitudinal), 10^6 psi	27.7	26.4	26.6	26.2
E_t (transverse), 10^6 psi	27.0	25.1	26.3	24.8
Compression				
F_{cy} (longitudinal), ksi	253.3	218.0	207.7	196.0
F_{cy} (transverse), ksi	231.7	204.7	188.7	169.7
E_c (longitudinal), 10^6 psi	31.2	30.5	29.4	27.8
E_c (transverse), 10^6 psi	29.9	29.0	28.0	26.8
Shear[b]				
F_{su} (longitudinal), ksi	162.8	U	U	U
F_{su} (transverse), ksi	161.5	U	U	U
Impact (V-notch Charpy)	U[c]	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	~60[d]	U	U	U

Properties	Temperature, F RT	500	700	900
<u>Axial Fatigue</u> (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	245	234	U	210
10^5 cycles, ksi	171	138	U	136
10^7 cycles, ksi	141	126	U	110
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	165	150	U	120
10^5 cycles, ksi	60	54	U	51
10^7 cycles, ksi	39	39	U	50
	Temperature, F RT	**800**	**900**	**950**
<u>Creep</u> (transverse)				
0.2% plastic deformation 100 hr, ksi	NA	NA	113	70
0.2% plastic deformation 1000 hr, ksi	NA	NA	98	46
<u>Stress Rupture</u> (transverse)				
Rupture 100 hr, ksi	NA	NA	175	150
Rupture 1000 hr, ksi	NA	NA	162	120
<u>Stress Corrosion</u>				
80% F_{ty}, 1000 hr max	Failed[f]	U	U	U
<u>Coefficient of Thermal Expansion</u>[g]				
5.87×10^{-6} in./in./F (77-600 F)				
<u>Density</u>[g] 0.282 lb/in.^{3}				

Footnotes appear on the following page.

FOOTNOTES FOR AFC-260 DATA

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Single-shear sheet type specimen, full thickness.

(c) U, unavailable; NA, not applicable.

(d) Value from Reference (1). A conditional value determined on 3-point loaded notched slow-bend specimens where W = 1.2, B = 0.6, and a_o = 0.6. The

The tests at Battelle were on single-edge-notched (3 x 12 in.) tension type specimens. No pop-in was detected. Load-strain curves were analyzed by the secant modulus method in ASTM STP 410 and proved to be invalid K_{Ic} tests (material too thin).

(e) "R" represents the algebraic ratio of the minimum to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

Specimen Number	Time, days cracking appeared (20X)	Time, days to fracture
7-1	29	37
7-2	21	28
7-3	22	26-28
7-4	38	46-50
7-5	22	30

(g) Values from References (2) and (3).

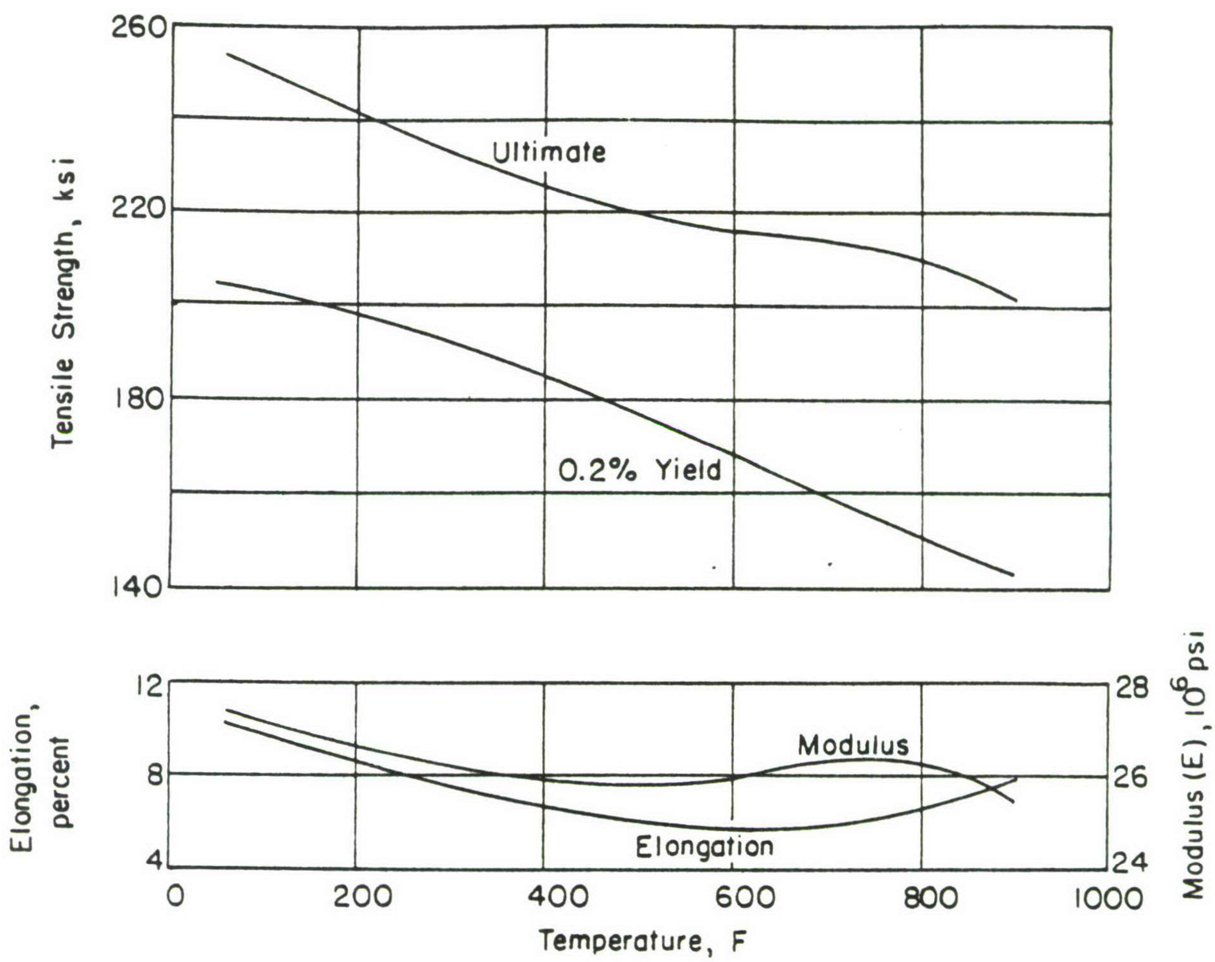


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AFC-260 STAINLESS STEEL SHEET

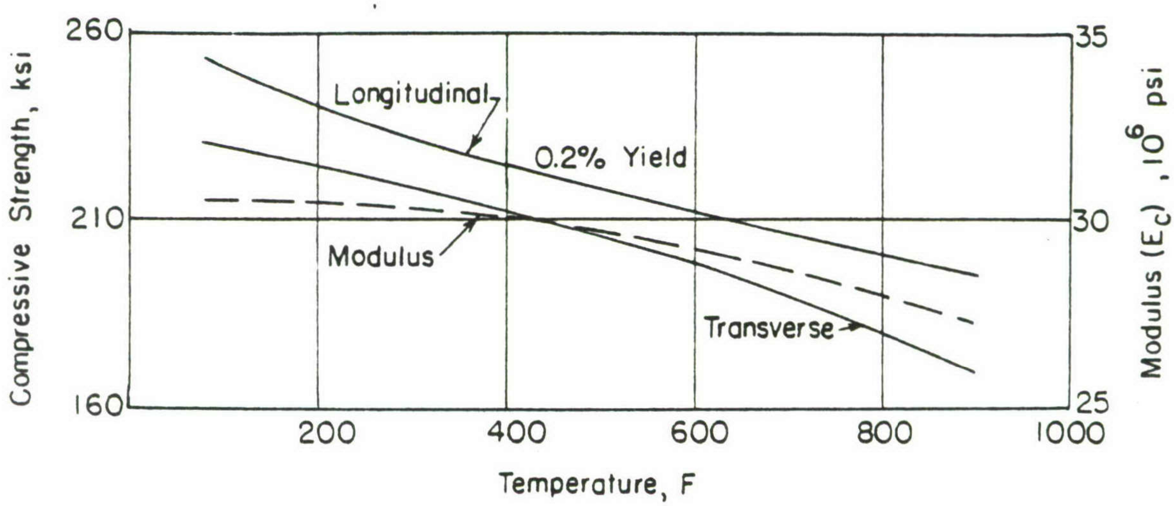


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES AFC-260 STAINLESS STEEL SHEET

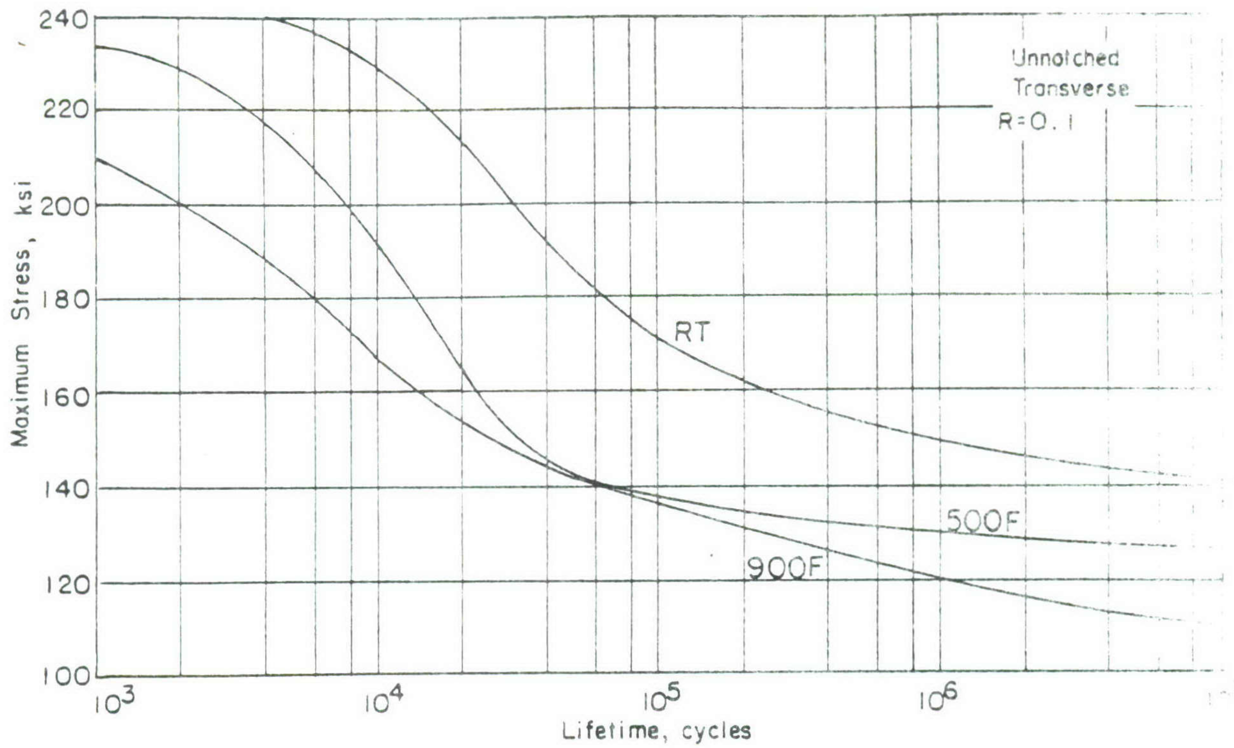


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED AFC-260 STAINLESS STEEL SHEET AT THREE TEMPERATURES

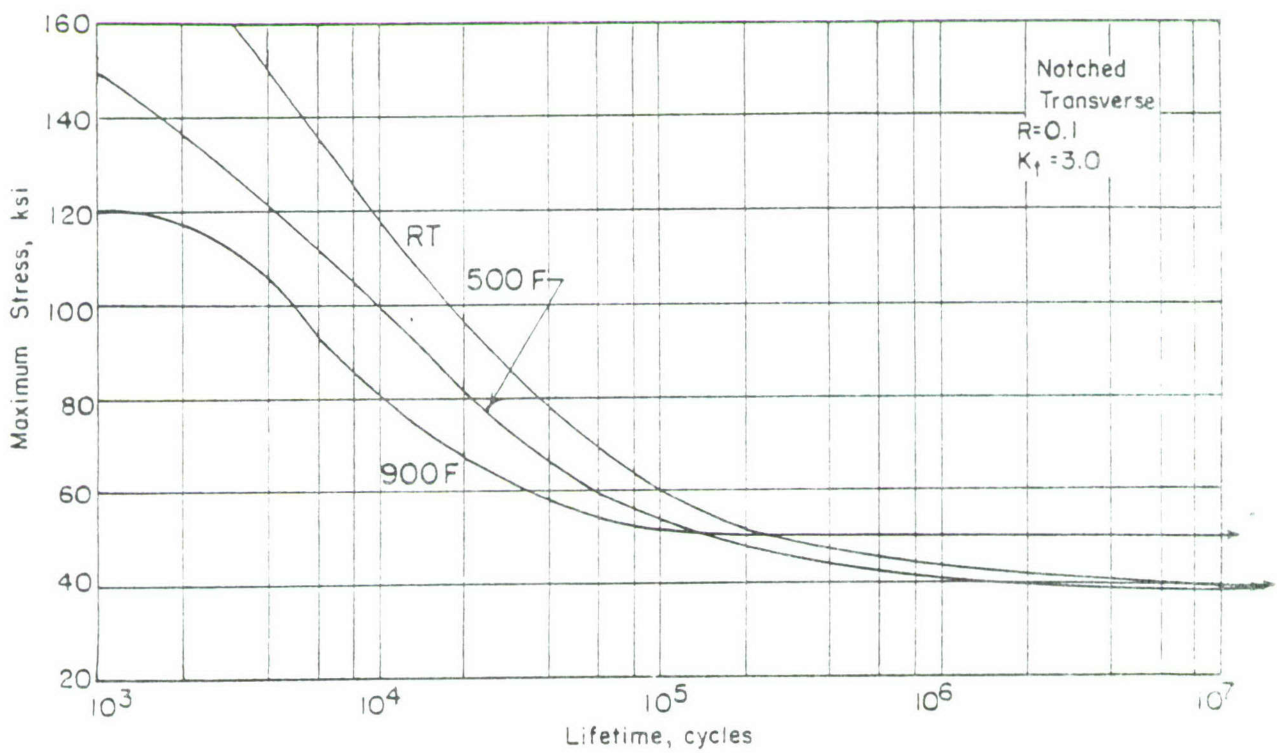


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t =3.0) AFC-260 STAINLESS STEEL SHEET AT THREE TEMPERATURES

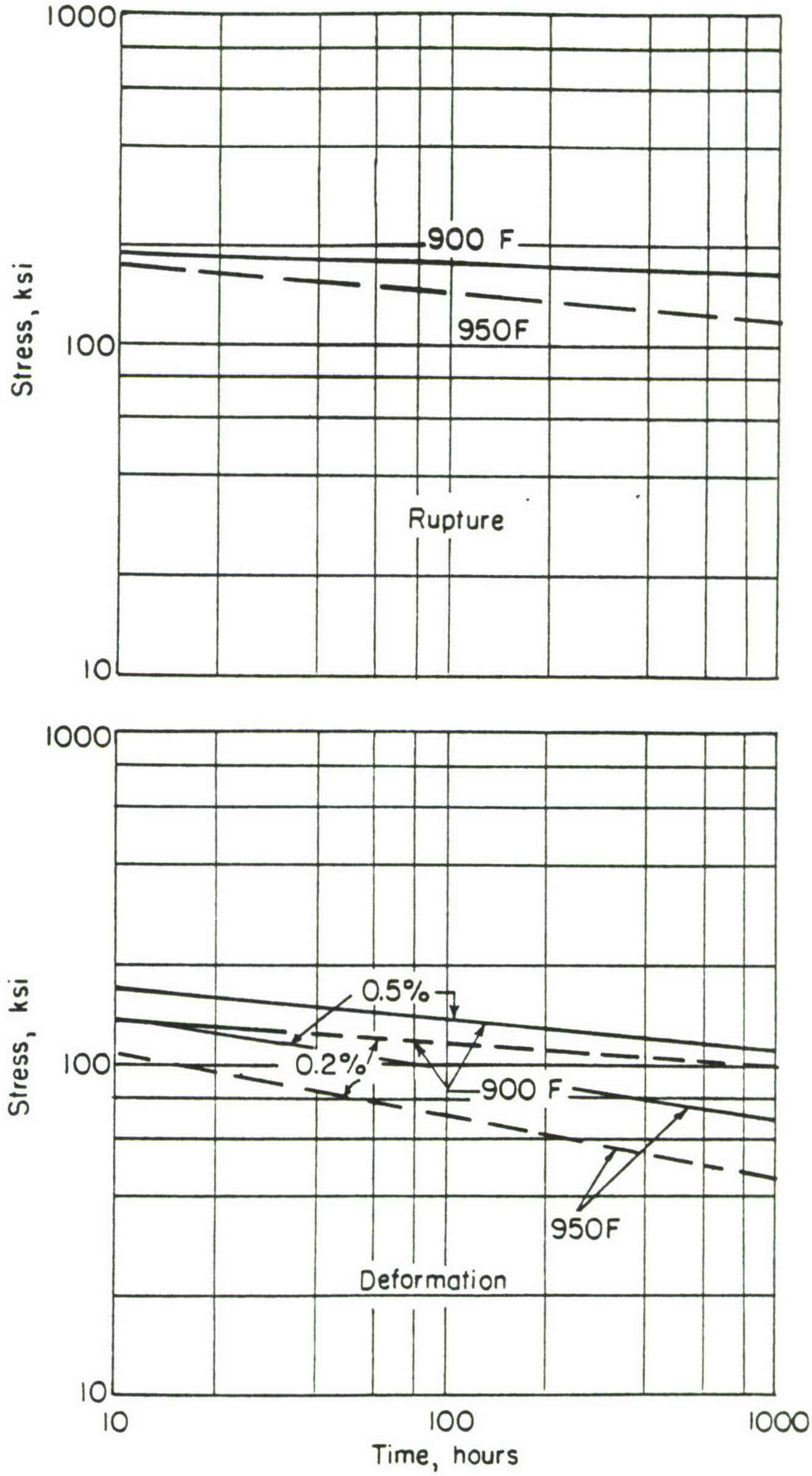


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR AFC-260 SHEET AT TWO TEMPERATURES

Ti-6Al-4V-3Co

The 3Co addition to the normal Ti-6Al-4V composition is a recent development to attempt to improve the properties of titanium alloys. Additions of 2 and 4 percent cobalt have also been studied. This particular material was obtained from the Cobalt Information Center in the form of round bar and was heat treated (as suggested by the Center) as follows: solution treat at 1450 F for 45 minutes, water quench, temper at 900 F for 4 hours. As can be seen from the data, the mechanical properties are improved over the conventional 6Al-4V alloy. However, the fatigue data show the material to be more notch sensitive then Ti-6Al-4V. From the creep and rupture data it can be seen that the 6Al-4V-3Co alloy has excellent creep-rupture strength at 500 F; however, it is very sensitive to small changes in stress. Also, at 700 and 850 F, short times at temperature show very good strength properties. A rapid drop in strength appears at long times at temperature.

Ti-6Al-4V-3Co Data[a]

Condition: STA
Thickness: 1/2- and 7/8-Inch Round Bar

Properties	Temperature, F RT	500	700	850
Tension				
F_{tu}, ksi	203.6	170.0	158.3	124.3
F_{ty}, ksi	194.6	145.0	129.0	108.3
e_t, percent in 2-in.	12.5	17.8	21.6	35.7
E_t, 10^6 psi	17.6	15.6	14.4	12.2
Compression				
F_{cy}, ksi	197.0	147.3	130.7	116.0
E_c, 10^6 psi	17.8	15.9	14.9	13.0
Shear[b]				
F_{su}, ksi	122.6	U[c]	U	U
Impact (V-notch Charpy)	U	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{\text{in.}}$ [d]	U	U	U	U
Axial Fatigue[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	214	200	U	156
10^5 cycles, ksi	167	140	U	106
10^7 cycles, ksi	135	135	U	95
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	115	115	U	105
10^5 cycles, ksi	50	50	U	41
10^7 cycles, ksi	46	46	U	40
Creep				
0.2% plastic deformation 100 hr, ksi	NA	110.0	58.0	6.0
0.2% plastic deformation 1000 hr, ksi	NA	90.0	38.5	2.0
Sress Rupture				
Rupture 100 hr, ksi	NA	165.0	123.0	61.0
Rupture 1000 hr, ksi	NA	165.0	119.0	40.0

Properties	Temperature, F			
	RT	500	700	850
Stress Corrosion				
F_{ty}, 1000 hr max	U	--	--	--
Coefficient of Thermal Expansion				
5.71×10^{-6} in./in./F (70-900 F)				
Density				

(a) Data are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Double-shear pin type specimen, 1/2-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Subject material was in round-bar form and not of sufficient size to conduct conventional fracture-toughness tests.

(e) "R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

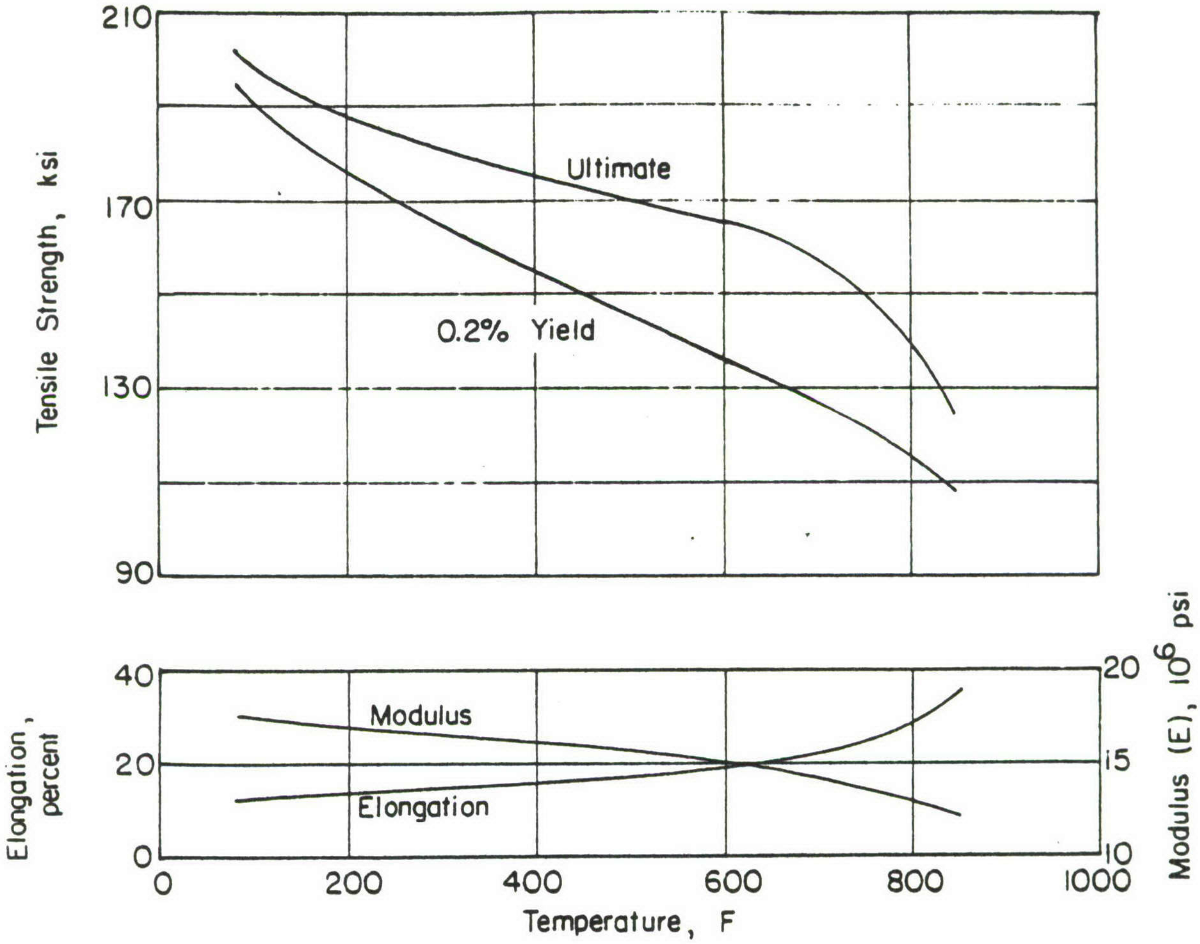


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V-3Co ROUND BAR

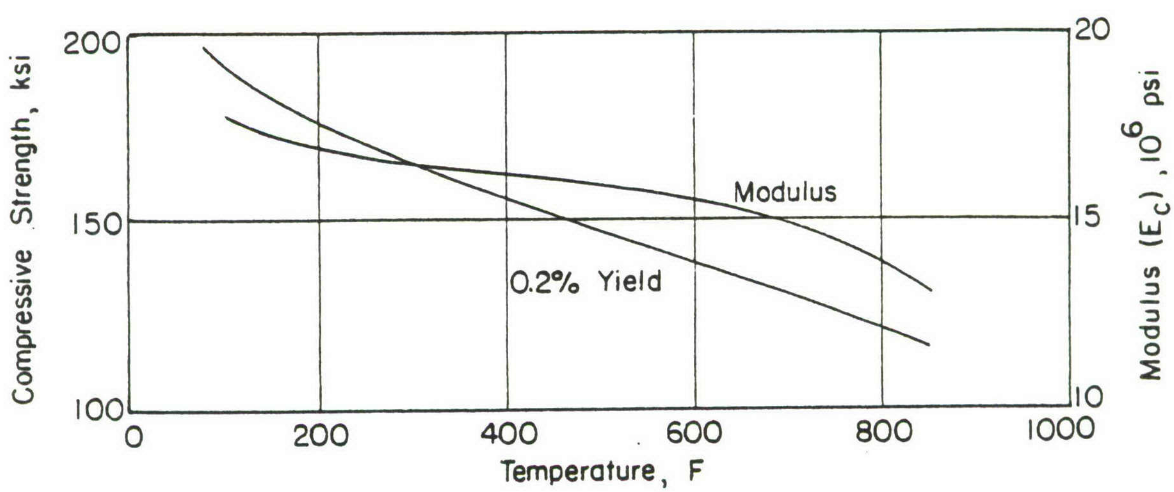


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF Ti-6Al-4V-3Co ROUND BAR

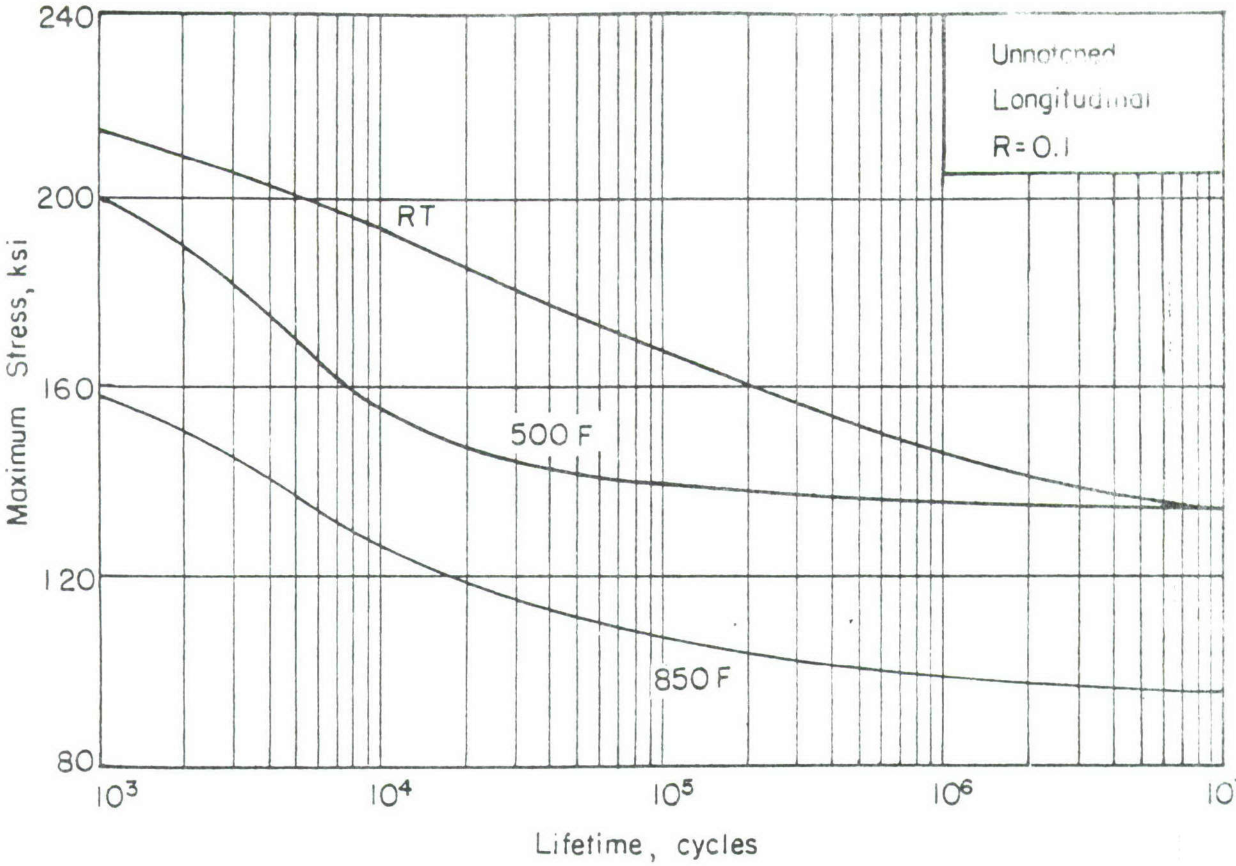


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR Ti-6Al-4V-3Co ROUND BAR AT THREE TEMPERATURES

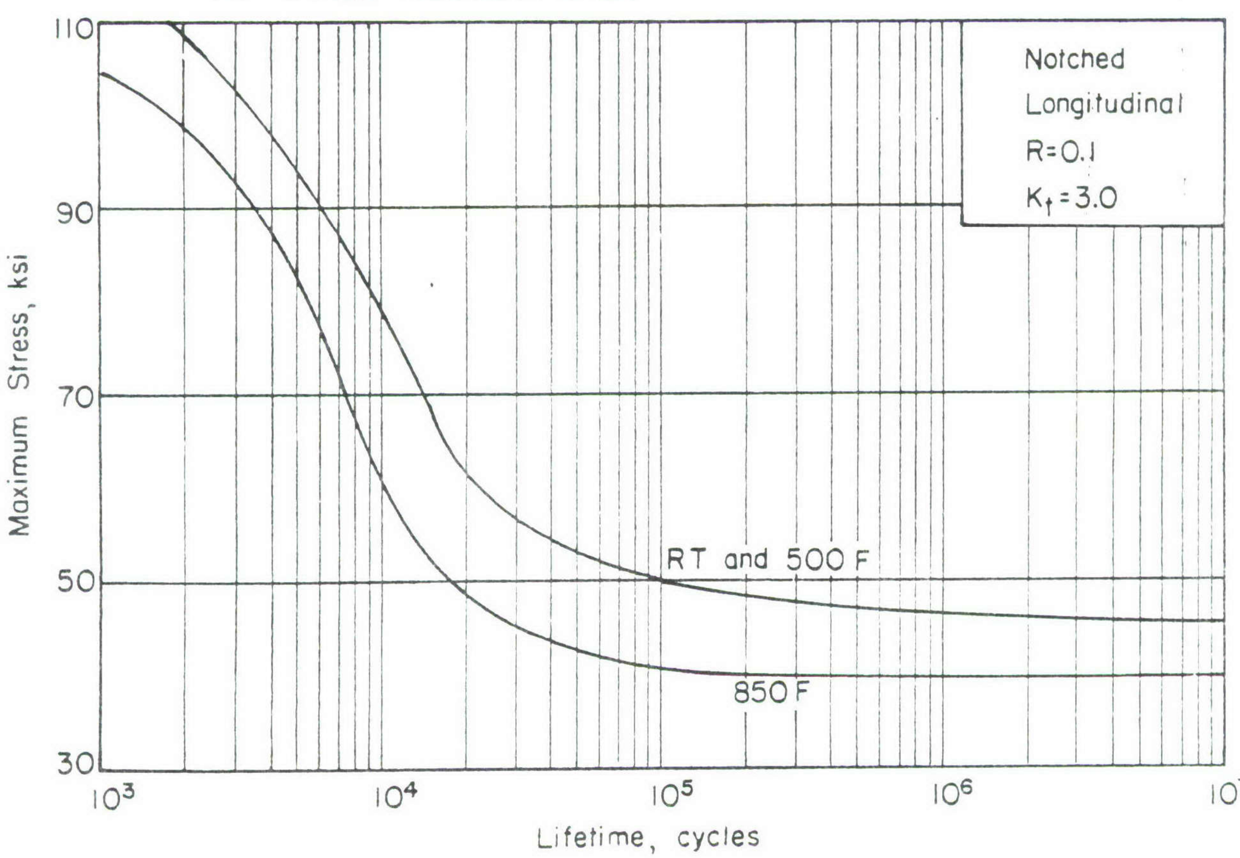


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K =3.0) Ti-6Al-4V-3Co ROUND BAR AT THREE TEMPERATURES

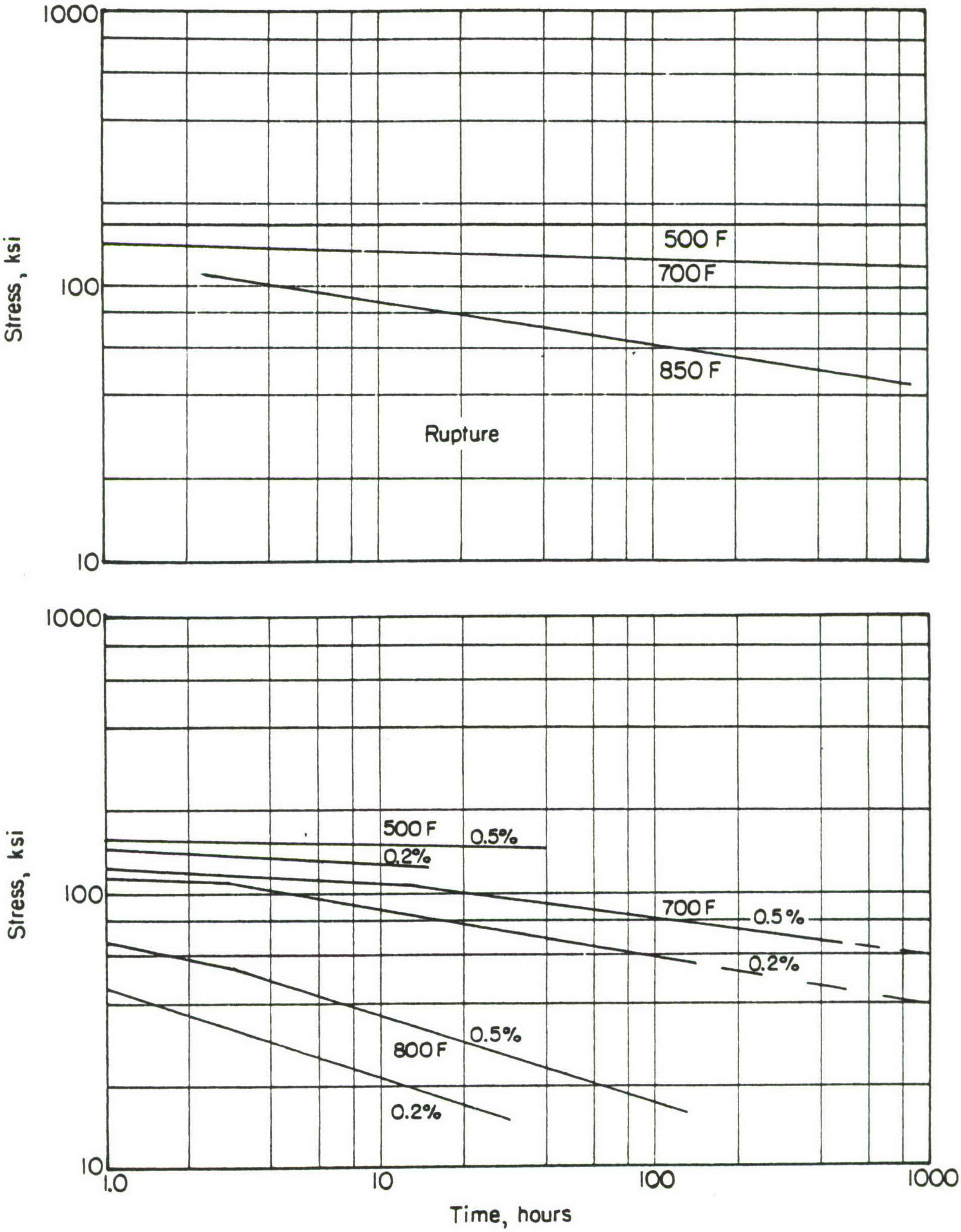


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V-3Co ROUND BAR

Beta III

Beta III is a simple quaternary solid-solution titanium alloy developed by the Crucible Steel Company under Air Force Contract AF 33(615)-2742. It is an all-beta alloy that has the ability to be cold rolled at least as easily as commercially pure titanium. Actually, tests show it can be cold rolled in excess of 90 percent without edge cracking. The alloy also was compounded to provide for relative ease in hot rolling.

The alloy can be heat treated over a range of tensile strengths by varying both solution-heat-treatment temperature and aging temperature. The treatment selected for this evaluation was the 950 F, 8 hours aged condition.

The composition of this material is as follows: 12.1 Mo, 6.5 Zr, 4.35 Sn, 0.04 Fe, 0.03 C, 0.014 N, 0.0095 H, 0.13 O, balance titanium.

BETA III TITANIUM DATA(a)

Condition: STA
Thickness: 0.062 Inch

Properties	Temperature, F: RT	400	600	850
Tension				
F_{tu} (longitudinal), ksi	187.3	164.0	157.7	144.7
F_{tu} (transverse), ksi	196.3	167.3	163.0	150.0
F_{ty} (longitudinal), ksi	175.0	146.0	139.0	126.7
F_{ty} (transverse), ksi	185.0	157.7	148.7	135.0
e_t (longitudinal), percent in 2 in.	8.5	6.7	6.7	11.0
e_t (transverse), percent in 2 in.	6.7	5.2	5.8	10.8
E_t (longitudinal), 10^6 psi	15.0	14.0	13.0	11.2
E_t (transverse), 10^6 psi	16.0	14.6	13.7	12.6
Compression				
F_{cy} (longitudinal), ksi	194.5	168.7	161.7	147.3
F_{cy} (transverse), ksi	211.0	182.3	173.7	159.3
E_c (longitudinal), 10^6 psi	15.9	15.5	15.1	13.5
E_c (transverse), 10^6 psi	17.5	16.7	16.2	14.5
Shear(b)				
F_{su} (longitudinal), ksi	117.0	U	U	U
F_{su} (transverse), ksi	118.0	U	U	U
Impact (V-notch Charpy), ft-lb	U(c)	U	U	U
Fracture Toughness, K_{Ic}, ksi$\sqrt{in.}$	(d)	U	U	U
Axial Fatigue (Transverse)(e)				
Unnotched, R = 0.1				
10^3 cycles, ksi	170	123	U	140
10^5 cycles, ksi	88	88	U	84
10^7 cycles, ksi	86	86	U	77
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	128	123	U	108
10^5 cycles, ksi	62	55	U	50
10^7 cycles, ksi	57	48	U	43

Properties	Temperature, F 500	600	700
Creep (Transverse)			
0.2% plastic deformation 100 hr, ksi	165.0	158.0	120.0
0.2% plastic deformation 1000 hr, ksi	163.0	151.0	80.0
Stress Rupture (Transverse)			
Rupture 100 hr, ksi	170	170	163.0
Rupture 1000 hr, ksi	169	169	150.0
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks(f)	U	U
Coefficient of Thermal Expansion			
4.8×10^{-6} in./in./F (RT to 900 F)			
Density(g) 0.183 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Single-shear sheet-type specimen, full thickness.

(c) U-unavailable; NA, not applicable.

(d) Center-notched (3 x 12) tension specimen. No pop-in detected. Load-strain curves were analyzed by the secant-offset method recommended by ASTM and proved to be invalid tests.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Room-temperature three-point bend test. No cracks appeared after alternate immersion in 3-1/2 percent NaCl for 1000 hours.

(g) Value from Reference (2).

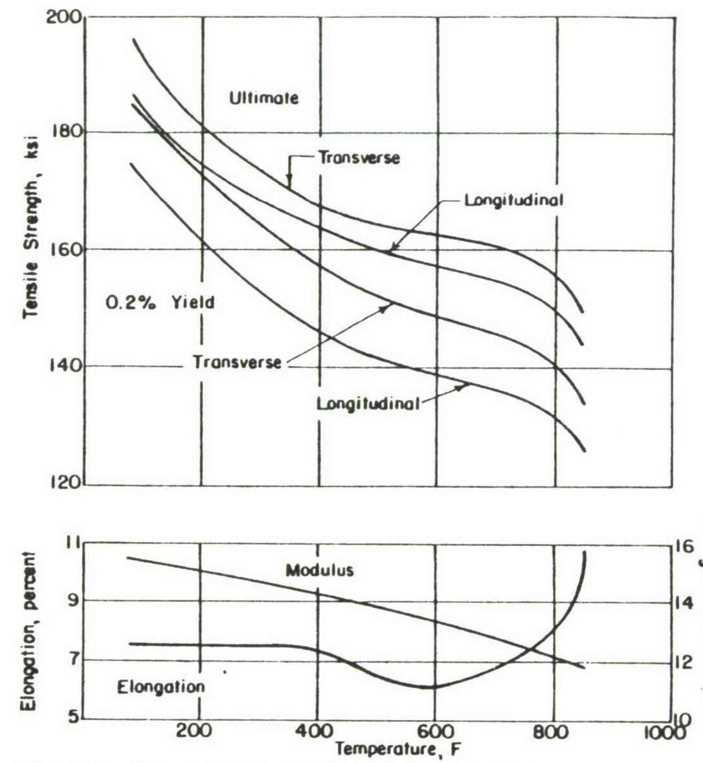


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA III TITANIUM SHEET

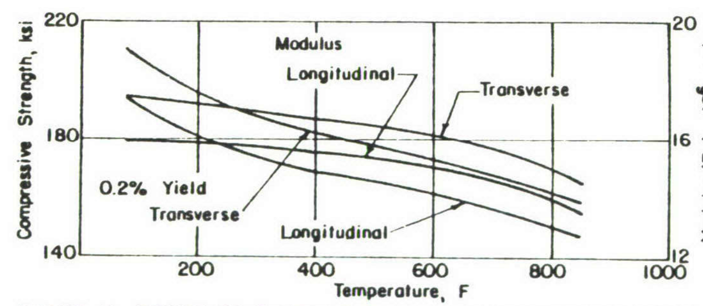


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF BETA III TITANIUM SHEET

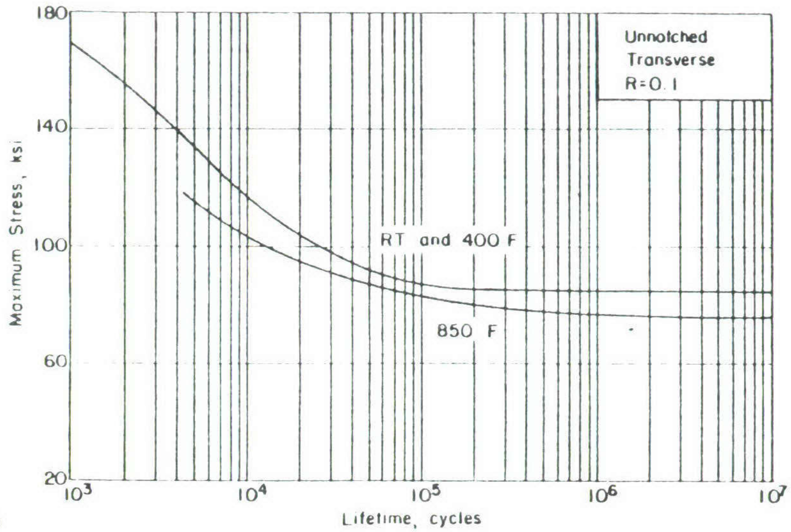


FIGURE 3. AXIAL-LOAD FATIGUE BEHAVIOR OF UNNOTCHED BETA III TITANIUM SHEET AT THREE TEMPERATURES

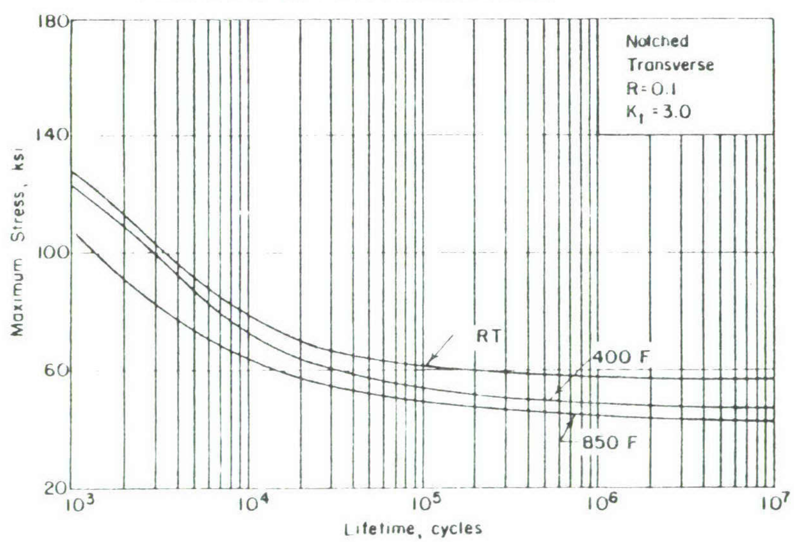


FIGURE 4. AXIAL-LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) BETA III TITANIUM SHEET AT THREE TEMPERATURES

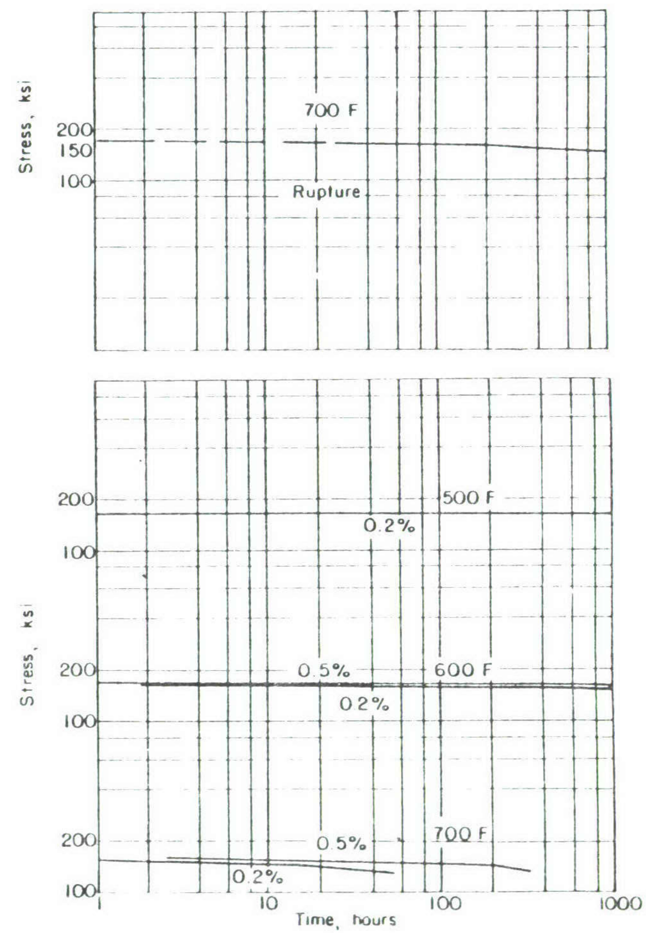


FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR BETA III TITANIUM SHEET

Ti-6Al-4V

Although Ti-6Al-4V sheet has been used for years, only within the past 2 years or so has the solution-treated- and overaged (STOA) heat treatment become of interest. This heat treatment has been an outgrowth of the SST development program. The problem was one of finding a new heat treatment that would provide higher resistance to stress-corrosion cracking and fracture strength that can be obtained with the normal mill anneal or STA treatment. The Boeing Company, together with the two major titanium producers, agreed upon the STOA condition to satisfy this desire. The heat treatment used for this testing program follows: solution treat at 1750 F for 10 minutes, water quench, age at 1250 F for 4 hours, air cool.

Recent discussions with TIMET personnel indicate that the producers will guarantee F_{tu} of 130 ksi for this condition.

6Al-4V TITANIUM SHEET DATA[a]

Condition: STOA
Thickness: 0.188 Inch

Properties	Temperature, F				
	-65	RT	300	500	700
Tensile					
F_{tu} (longitudinal), ksi	165.0	140.8	121.0	110.0	103.5
F_{tu} (transverse), ksi	171.8	146.8	128.0	117.0	110.0
F_{ty} (longitudinal), ksi	153.0	131.5	105.0	89.4	81.0
F_{ty} (transverse), ksi	162.0	140.5	112.0	96.8	89.7
e_t (longitudinal), percent in 2 in.	9.0	10.8	12.5	12.0	10.2
e_t (transverse), percent in 2 in.	14.0	14.5	14.5	13.2	11.0
E_t (longitudinal), 10^6 psi	17.3	16.8	16.1	15.2	14.0
E_t (transverse), 10^6 psi	18.8	18.4	17.6	17.1	14.8
Compression					
F_{cy} (longitudinal), ksi		143.0	116.5	98.4	88.1
F_{cy} (transverse), ksi		163.0	130.5	111.5	99.3
E_c (longitudinal), 10^6 psi		17.8	17.0	16.0	14.8
E_c (transverse), 10^6 psi		19.0	18.1	17.2	16.4
Shear[b]					
F_{su}, (longitudinal), ksi		90.2	U	U	U
F_{su}, (transverse), ksi		98.0	U	U	U
Fracture Toughness[d], K_{Ic}, ksi$\sqrt{in}$		U[c]	U	U	U
Axial Fatigue (Transverse)[e]					
Unnotched, R = 0.1					
10^3 (K_t = 1) (R = 0.1), ksi		145	115		105
10^5 (K_t = 1) (R = 0.1), ksi		122	81		86
10^7 (K_t = 1) (R = 0.1), ksi		111	72		80
Notched (K_t = 3.0), R = 0.1					
10^3 (K_t = 3) (R = 0.1), ksi		123	111		100
10^5 (K_t = 3) (R = 0.1), ksi		51	43		40
10^7 (K_t = 3) (R = 0.1), ksi		46	40		37

Properties	RT	Temperature, F 500	600	700
Creep				
0 2% elongation 100 hr, ksi	NA	110	100	80
0 2% elongation 1000 hr, ksi	NA	108	98	68
Stress Rupture				
Rupture 100 hr, ksi	NA	120	114	106
Rupture 1000 hr, ksi	NA	118	112	102
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks[f]			
Coefficient of Thermal Expansion				
5.8×10^{-6} in./in./F (RT to 1000 F)				
Density 0.160 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and rupture values are from curves generated using a greater number of tests.

(b) Single-shear sheet-type specimen, full thickness.

(c) U = unavailable

(d) Tests at room temperature proved to be marginal by existing criteria.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle, that is $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

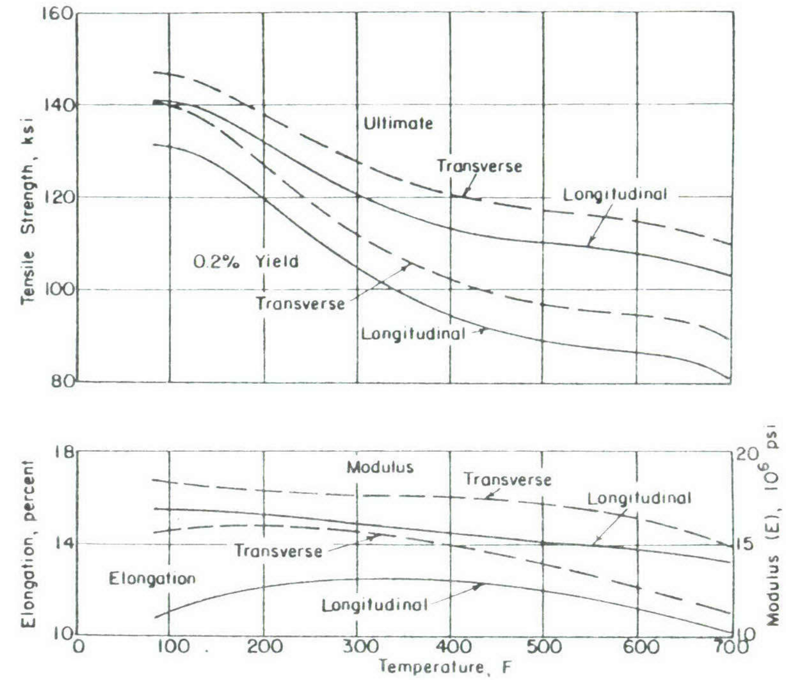


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

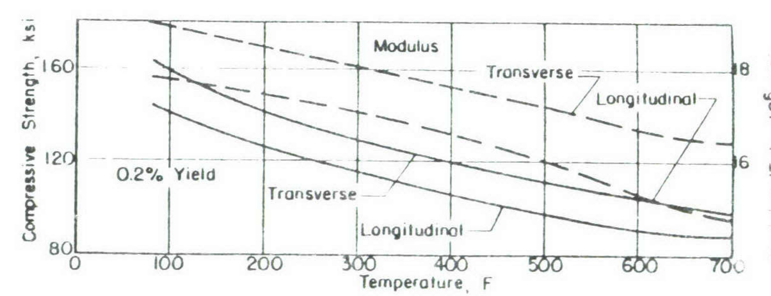


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

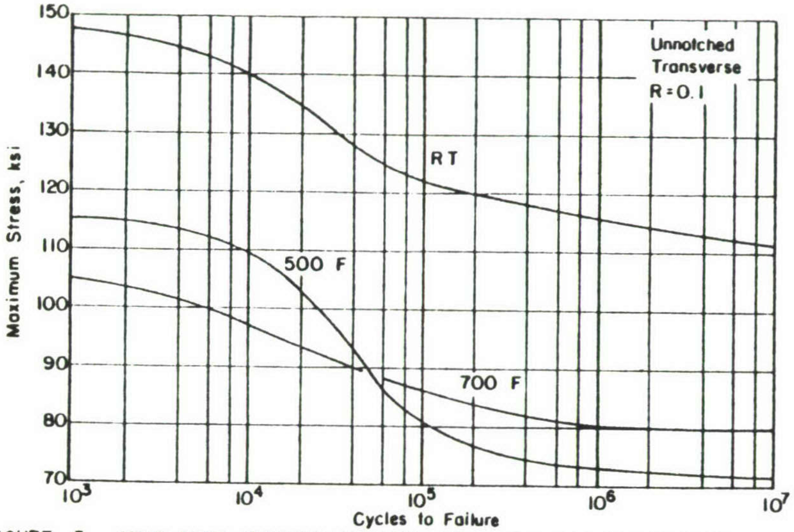


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

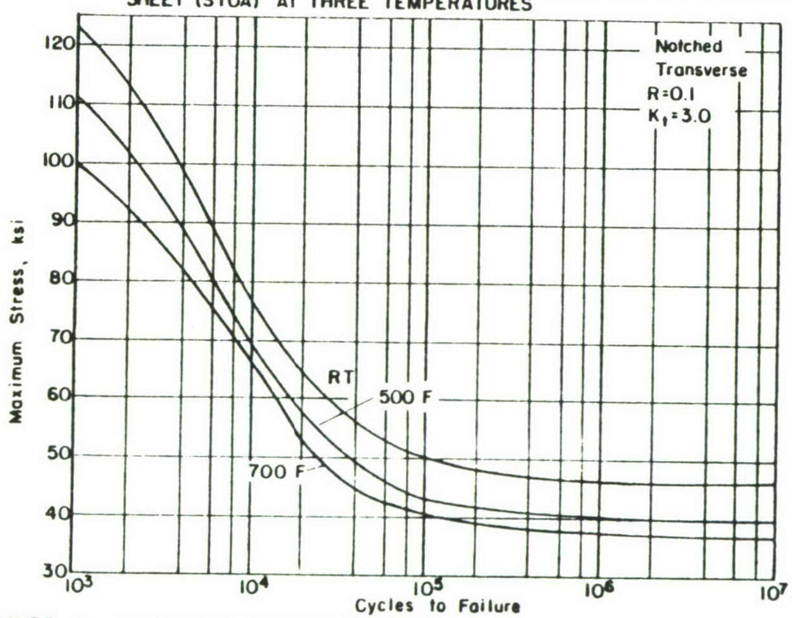


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

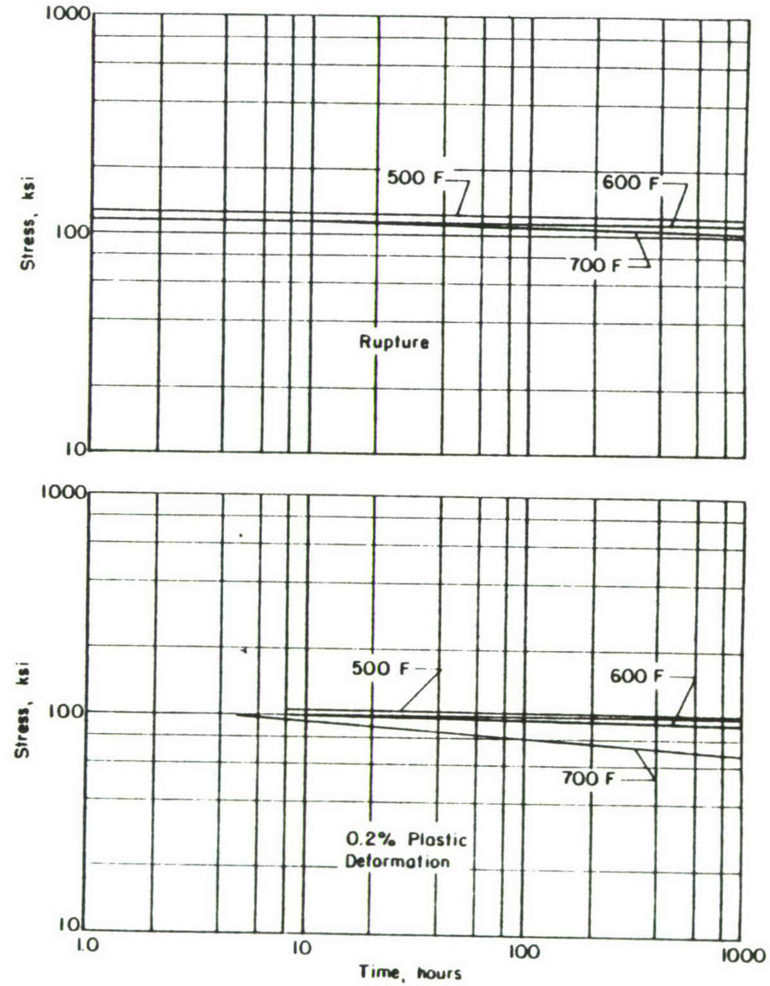


FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR Ti-6Al-4V ALLOY SHEET

6Al-4V Titanium Extrusions

This alloy is one of the most widely used alloys of titanium. For this evaluation a thin "T" section extrusion was chosen to obtain properties for the material after the drawing process.

Approximately 60 feet of the thin extrusion was supplied GFM in 30-inch lengths.

All of the "T" sections were extruded from billets of approximately 3.5 inches in diameter by 7 to 8 inches in length. The target thickness of 0.040 inches was attained by three draw passes plus chemical removal of 0.002 inches per side to remove contamination. After the final draw and stretch straightening operation the shapes were vacuum annealed at 1325 F for 1-1/2 hours and argon cooled to room temperature.

In order to obtain enough specimen material and maintain specimen uniformity all specimens tested were in the longitudinal direction. The vertical section of the "T" was removed and the center of the "T" was the centerline of all specimens.

Ti-6A-4V "T" Extrusion Data[(a)]
Condition: Drawn and Annealed
Thickness: 0.04-inch nominal

Properties	Temperature, F			
	RT	400	700	900
Tension (longitudinal)				
F_{tu}, ksi	154.0	123.3	106.7	94.4
F_{ty}, ksi	144.7	109.3	88.8	80.9
e, percent in 2-in	11.2	12.0	9.2	17.0
E, 10^6 psi	16.0	14.5	12.9	11.0
Compression (longitudinal)				
F_{cy}, ksi	147.0	111.3	97.1	86.1
E_c, 10^6 psi	17.9	16.6	15.5	14.5
Impact[(b)]	U[(e)]	U	U	U
Fracture Toughness[(c)]	U	U	U	U
Shear (longitudinal)[(d)]				
F_{su}, ksi	93.0	U	U	U
Axial Fatigue (longitudinal)[(f)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	148	140	126	U
10^5 cycles, ksi	82	78	78	U
10^7 cycles, ksi	60	60	70	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	125	118	109	U
10^5 cycles, ksi	59	45	40	U
10^7 cycles, ksi	50	30	30	U
Creep (longitudinal)				
0.2% plastic deformation, 100 hr	NA	102[(g)]	66	11
0.2% plastic deformation, 1000 hr	NA	98[(g)]	54	6

Ti-6A-4V "T" Extrusion Data (continued)

Properties	RT	400	700	900
	Temperature, F			
Stress Rupture (longitudinal)				
Rupture, 100 hr	NA	112(g)	102	56
Rupture, 100 hr	NA	111(g)	98	35
Stress Corrosion				
80% F_{ty}, 100 hr max	No Cracks(h)			
Coefficient of Thermal Expansion				
5.8×10^{-6} in./in./F(RT to 1000 F)				
Density				
0.160 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Material not of sufficient thickness for Charpy tests.

(c) Material not of sufficient size for K_{IC} tests.

(d) Single-shear sheet-type specimen.

(e) U, unavailable; NA, not applicable.

(f) "R" represents the algebraic ration of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Data for 500 F.

(h) Room-temperature three point bend test. Alternate immersion in 3-1/2 percent NaCl.

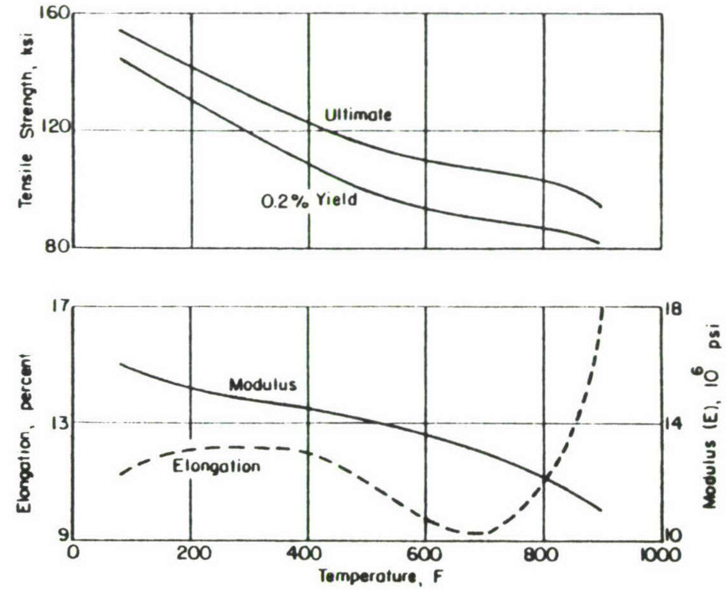


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

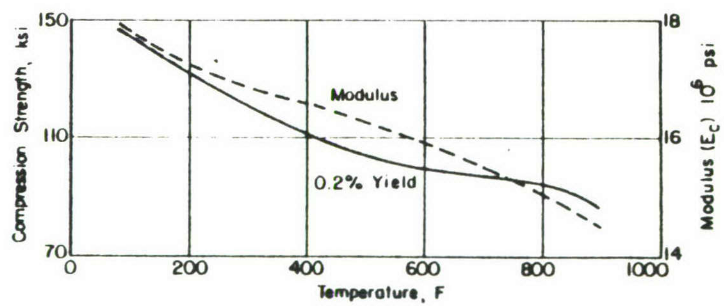


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

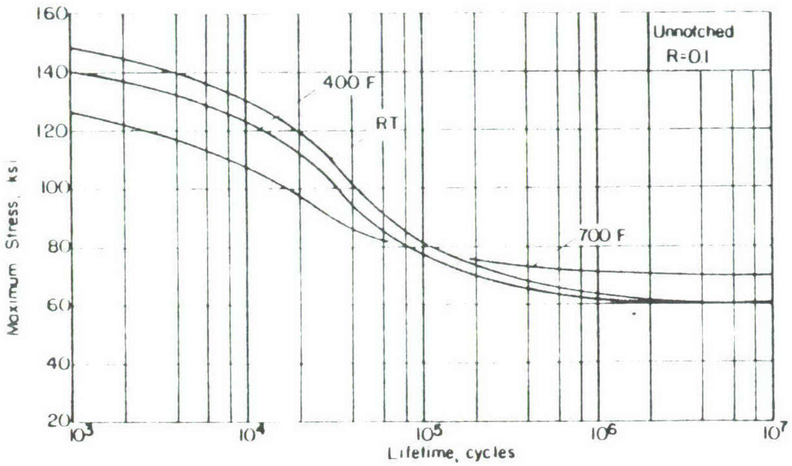


FIGURE 3 AXIAL LOAD FATIGUE RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS AT THREE TEMPERATURES

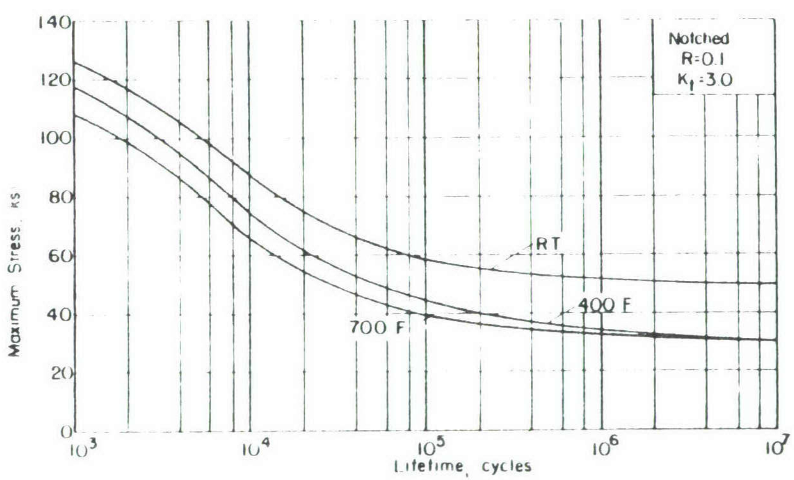


FIGURE 4 AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) Ti-6Al-4V "T" EXTRUSIONS AT THREE TEMPERATURES

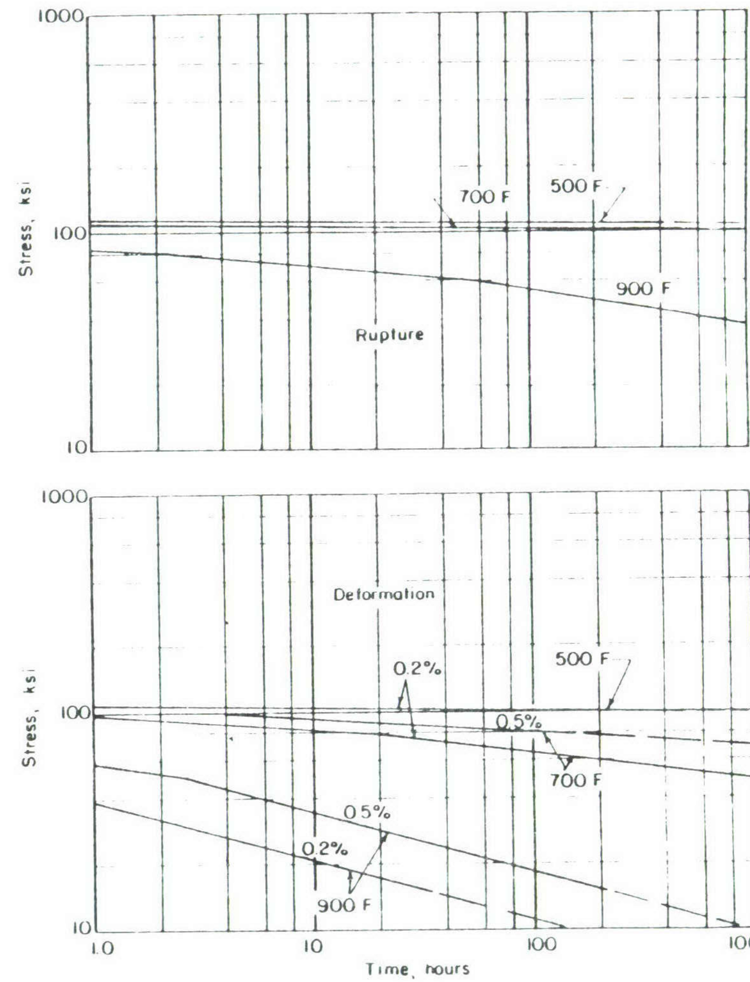


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V "T" EXTRUSIONS

300M

300M is one of the modifications to 4340 steel that currently is being considered for use as an ultrahigh-strength steel. The low-alloy steel combines high hardenability with relatively good impact strength and ductility. Formerly called "Tricent" and used in the 200 to 220-ksi strength range, 300M is now considered useful at the 280-ksi strength level.

The composition of this material is as follows:

Carbon	0.43
Silicon	1.68
Manganese	0.70
Phosphorus	0.010
Sulfur	0.010
Nickel	1.93
Chromium	0.79
Molybdenum	0.39
Aluminum	0.15
Vanadium	0.07
Iron	Balance

All of the specimens used in this test program were obtained from the flange section of a large I-beam forging with a cross section of approximately 20 inches by 10 inches. The flange section had a cross section of approximately 6 inches by 10 inches. Specimens were heat treated to the 280-ksi strength level as follows: 1600 F, quench in warm oil, temper 2 + 2 hours at 575 F.

300M STEEL DATA[a]

Condition: Quenched and Tempered

Properties	Temperature, F			
	RT	250	400	550
Tension				
F_{tu} (longitudinal), ksi	292.0	294.0	295.0	260.0
F_{tu} (transverse), ksi	293.0	296.0	296.0	263.0
F_{tu} (short transverse), ksi	291.0	--	--	--
F_{ty} (longitudinal), ksi	247.0	234.0	209.0	191.0
F_{ty} (transverse), ksi	247.0	237.0	212.0	187.0
F_{ty} (short transverse), ksi	245.0	--	--	--
e_t (longitudinal), percent in 1 in.	12.0	11.0	21.0	22.0
e_t (transverse), percent in 1 in.	11.0	11.0	19.2	21.8
e_t (short transverse), percent in 1 in.	11.0	--	--	--
RA (longitudinal), percent	43.6	36.8	49.5	56.5
RA (transverse), percent	37.7	34.3	42.8	55.0
RA (short transverse), percent	40.1	--	--	--
E_t (longitudinal), 10^6 psi	29.4	26.1	26.9	23.1
E_t (transverse), 10^6 psi	29.5	27.6	27.3	25.6
E_t (short transverse), 10^6 psi	29.0	--	--	--
Compression				
F_{cy} (longitudinal), ksi.	264.5	247.5	229.5	205.5
F_{cy} (transverse), ksi	267.0	251.0	231.0	210.0
E_c (longitudinal), 10^6 psi	30.1	29.5	29.1	27.7
E_c (transverse), 10^6 psi	30.7	30.1	29.2	27.8
Shear[b]				
F_{su} (longitudinal), ksi	179.0	U[c]	U	U
F_{su} (transverse), ksi	179.2	U	U	U
Impact (V-notch Charpy), ft-lb	15.5	16.5	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	69.2[d]	U	U	U

Properties	Temperature, F		
	RT	300	500
Axial Fatigue (Longitudinal)(e)			
Unnotched, R = 0.1			
10^3 cycles, ksi	285	280	270
10^5 cycles, ksi	172	160	154
10^7 cycles, ksi	140	132	132
Notched (K_t = 3.0), R = 0.1			
10^3 cycles, ksi	170	160	146
10^5 cycles, ksi	56	50	56
10^7 cycles, ksi	30	42	48
Creep and Stress Rupture(f)	NA	NA	U
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks(g)	U	U
Coefficient of Thermal Expansion(h)			
8.1×10^{-6} in./in./F (0 to 1200 F)			
Density(h) 0.283 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 1/4-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Average of 5 chevron-notched slow-bend tests.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Specimens did not go to 0.2 percent elongation or to rupture at 500 F when stressed to the tensile yield strength. Specimen stressed at 250 ksi reached 0.2 percent deformation in 1 hour, but did not rupture in 1000 hours.

(g) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

(h) Value from Reference (2).

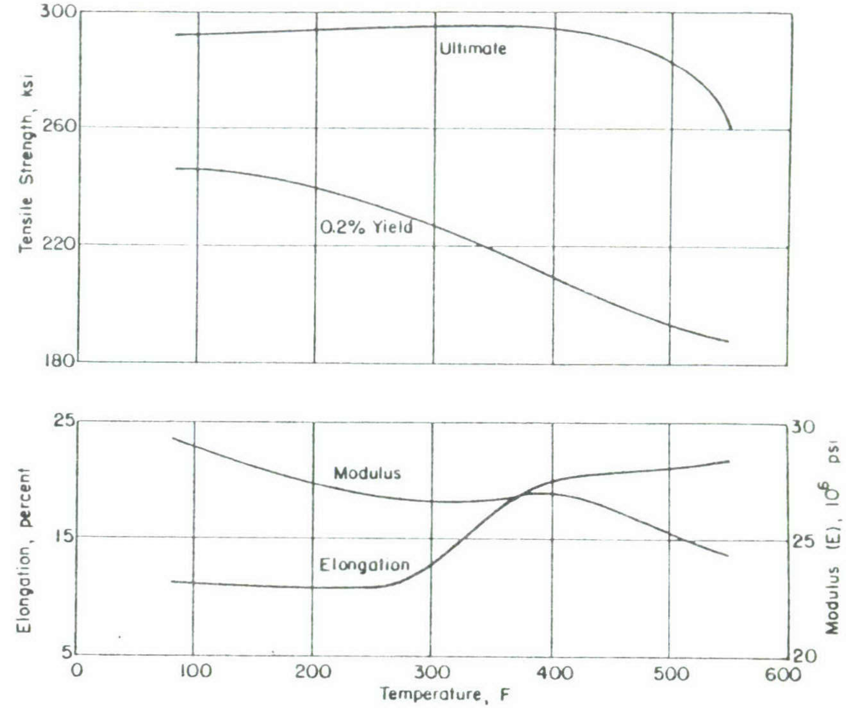


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 300M FORGINGS

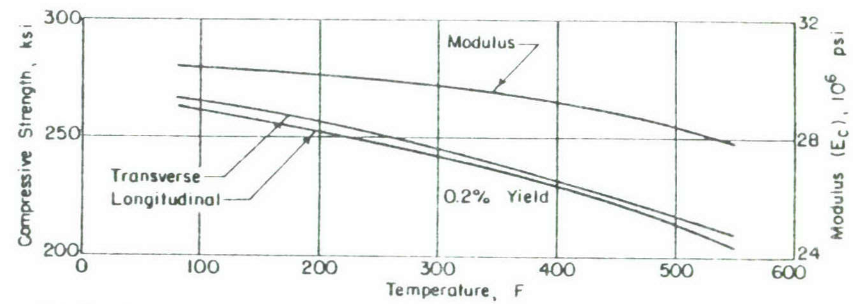


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 300M FORGINGS

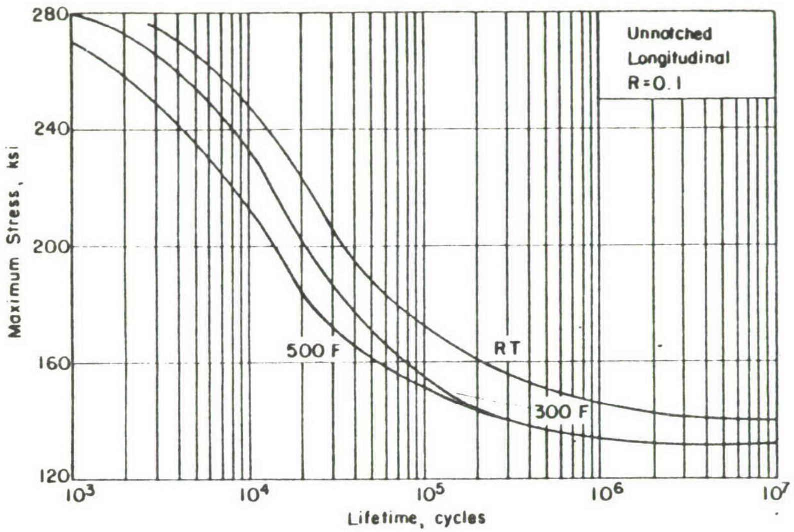


FIGURE 3. AXIAL-LOAD FATIGUE BEHAVIOR OF UNNOTCHED 300M FORGING AT THREE TEMPERATURES

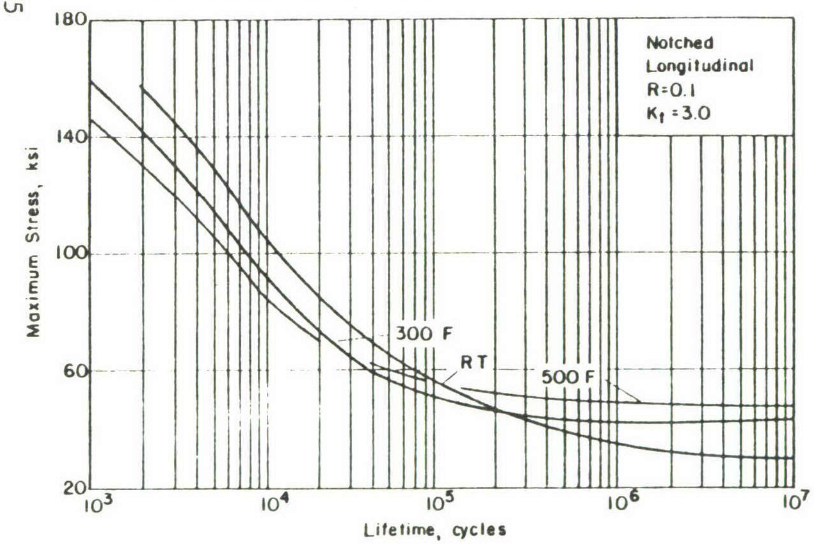


FIGURE 4. AXIAL-LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t =3.0) 300M FORGING AT THREE TEMPERATURES

7049-T73

Alloy X7049 is a new development by Kaiser Aluminum and Chemical Corporation. It was designed to have a strength level in the range of 7075-T6 and 7079-T6, coupled with a high resistance to stress-corrosion cracking. The temper designation -T73 has been assigned to cover the alloy with these characteristics. The initial development and production has been in the form of die forgings and hand forgings.

The threshold level for stress-corrosion cracking is reported by Kaiser to be 45 ksi.

All specimens used for this test program were from a 5-inch-thick forging. The composition of this forging is as follows:

Si	0.07
Fe	0.13
Mn	0.01
Cu	1.48
Mg	2.45
Cr	0.16
Zn	7.50
Al	Balance

7049 DATA(a)

Condition: T73
Thickness: 5-Inch Forging

Properties	Temperature, F			
	RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	72.9	62.2	49.7	16.7
F_{tu} (transverse), ksi	74.9	62.3	50.3	18.1
F_{tu} (short transverse), ksi	70.9	--	--	--
F_{ty} (longitudinal), ksi	64.2	59.7	49.0	16.6
F_{ty} (transverse), ksi	66.5	60.1	49.5	18.0
F_{ty} (short transverse), ksi	61.9	--	--	--
e_t (longitudinal), percent in 2 in.	8.8	14.8	20.0	29.3
e_t (transverse), percent in 2 in.	11.0	15.7	18.0	30.0
e_t (short transverse), percent in 2 in.	6.0	--	--	--
E_t (longitudinal), 10^6 psi	10.2	9.9	8.8	7.1
E_t (transverse), 10^6 psi	10.6	10.2	8.2	6.9
E_t (short transverse), 10^6 psi	9.9	--	--	--
Compression				
F_{cy} (longitudinal), ksi	66.8	64.0	53.3	20.4
F_{cy} (transverse), ksi	67.6	63.0	51.9	19.7
E_c (longitudinal), 10^6 psi	10.6	9.4	8.4	8.2
E_c (transverse), 10^6 psi	10.6	9.9	8.6	7.9
Shear(b)				
F_{su}, (longitudinal), ksi	47.8	U	U	U
F_{su}, (transverse), ksi	47.7	U	U	U
Impact (V-notch charpy), ft-lb	4.1(c)	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	31.7	(d)	U	U

Properties	RT	250	350	500
	Temperature, F			
Axial Fatigue (Transverse)(e)				
Unnotched, R = 0.1				
10^3 cycles, ksi	73	71	70	--
10^5 cycles, ksi	57	53	48	--
10^7 cycles, ksi	46	40	38	--
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	50	50	50	--
10^5 cycles, ksi	21	20	19	--
10^7 cycles, ksi	16	13	11	--
Creep (Transverse)				
0.2% plastic deformation 100 hr, ksi	NA	42	15	4
0.2% plastic deformation 1000 hr, ksi	NA	36	9	2.7
Stress Rupture (Transverse)				
Rupture 100 hr, ksi	NA	50	21	5.6
Rupture 1000 hr, ksi	NA	40	13.5	4.3
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks(f)			
Coefficient of Thermal Expansion				
13.0×10^{-6} in./in./F (RT to 212 F)				
Density 0.099 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 1/2-inch diameter.

(c) 4.1 at RT, 3.5 at -100 F, 3.2 at -320 F.

(d) Average of six chevron-notched slow-bend tests. Tests at 250 F proved to be invalid.

(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle, that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

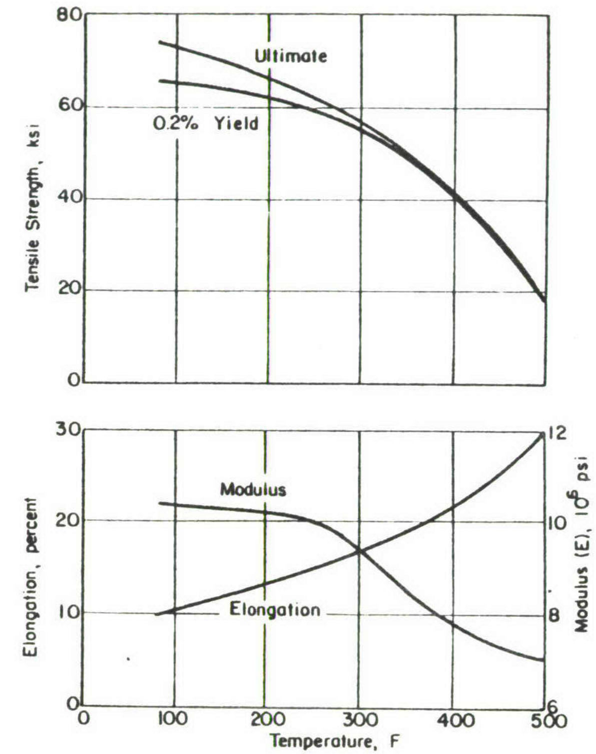


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

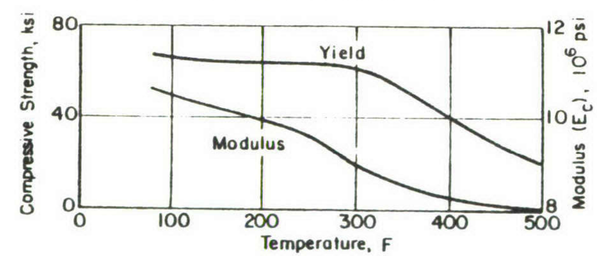


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

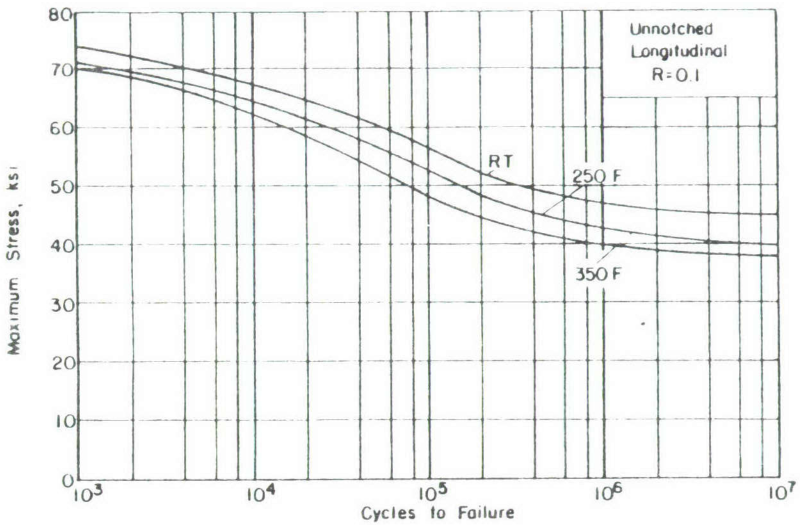


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 7049-T73 ALUMINUM FORGING AT THREE TEMPERATURES

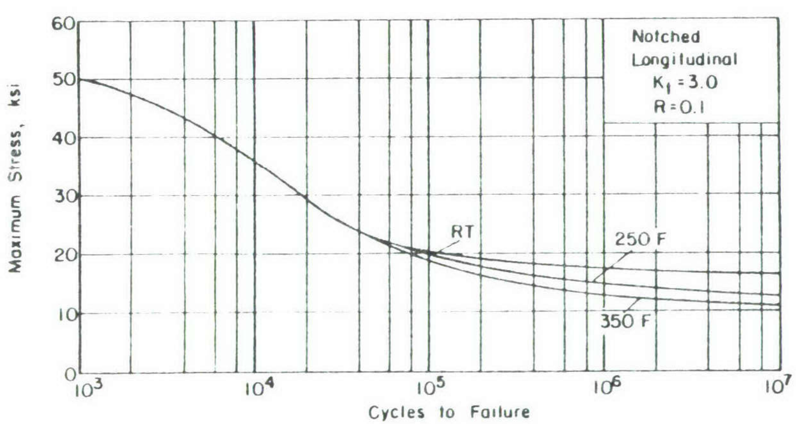


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7049-T73 ALUMINUM FORGING AT THREE TEMPERATURES

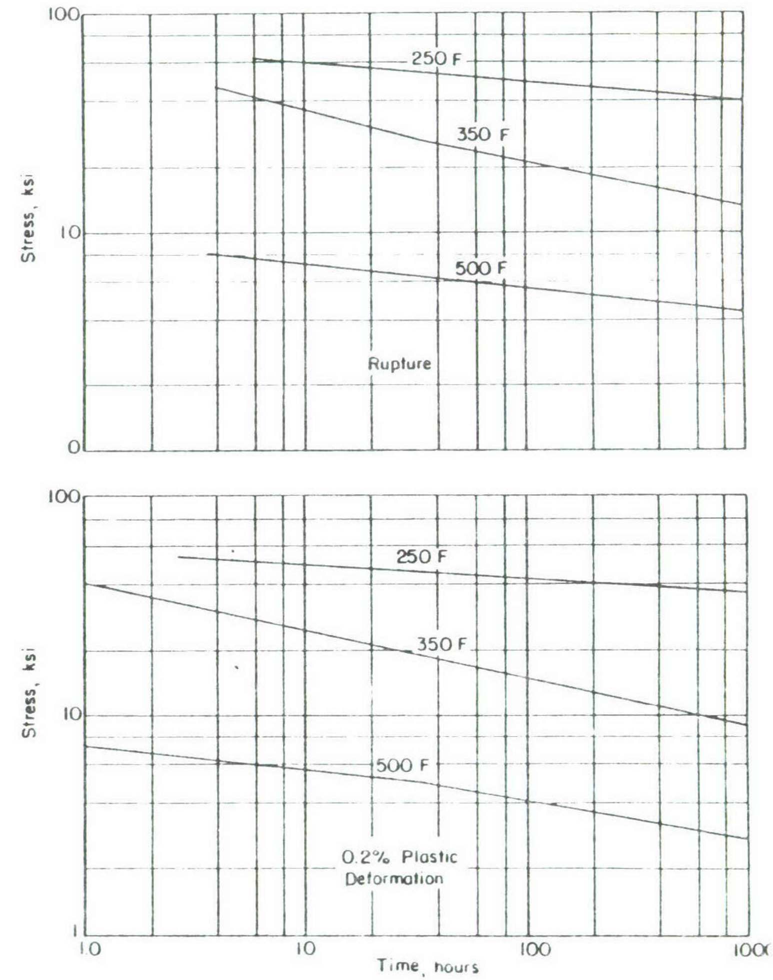


FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR 7049-T73 ALUMINUM FORGINGS

7178-T76

Alloy 7178 is a heat-treatable aluminum alloy containing zinc, copper, and magnesium as hardeners. At present it is one of the strongest wrought aluminum alloys produced. Its general properties are similar to those of alloy 7075, but its use is limited to a rather narrow range of thickness owing to its limited hardenability.

The -T76 temper for 7178 was developed as compromise between the exfoliation resistance of 7075-T73 and the structural capability of 7075-T6. It was to achieve an increase in resistance to exfoliation over that of 7075-T6 while maintaining a high level of strength and fracture toughness characteristics.

The nominal composition of 7178 is as follows:

Silicon	0.50
Iron	0.70
Copper	1.6-2.4
Manganese	0.30
Chromium	0.18-0.40
Zinc	6.3-7.3
Titanium	0.20
Aluminum	Balance
Magnesium	2.4-3.1

7178 Data[a]

Condition: -T76
Thickness: 0.215-Inch Sheet

Properties	Temperature, F RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	80.2	63.8	50.9	18.7
F_{tu} (transverse), ksi	81.6	65.4	51.7	17.4
F_{ty} (longitudinal), ksi	71.7	63.3	50.2	18.2
F_{ty} (transverse), ksi	71.0	62.4	49.8	17.0
e_t (longitudinal), percent in 2 in.	10.7	14.8	16.3	24.8
e_t (transverse), percent in 2 in.	9.5	16.5	17.7	23.2
E_t (longitudinal), 10^6 psi	10.0	9.6	8.6	6.4
E_t (transverse), 10^6 psi	10.2	10.1	9.4	7.3
Compression				
F_{cy} (longitudinal), ksi	76.2	69.6	57.4	20.2
F_{cy} (transverse), ksi	80.3	73.5	60.6	19.6
E_c (longitudinal), 10^6 psi	10.5	10.2	9.1	8.6
E_c (transverse), 10^6 psi	10.9	10.2	10.1	9.0
Shear[b]				
F_{su} (longitudinal), ksi	53.4	U[c]	U	U
F_{su} (transverse), ksi	54.0	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$[d]	27.7	U	U	U

Properties	Temperature F, RT	250	350	500
Axial Fatigue (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	85	78	65	--
10^5 cycles, ksi	38	36	35	--
10^7 cycles, ksi	31	24	21	--
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	58	45	43	--
10^5 cycles, ksi	22	18	16	--
10^7 cycles, ksi	18	14	12	--
Creep (transverse)	RT	350	450	600
0.2% plastic deformation 100 hr, ksi	NA	17	6.6	2.5
0.2% plastic deformation 1000 hr, ksi	NA	11	4.6	1.8
Stress Rupture (transverse)				
Rupture 100 hr, ksi	NA	22	9.5	4.3
Rupture 1000 hr, ksi	NA	15	7.0	3.3
Stress Corrosion				
80% F_{ty}, 1000 hr max No cracks[f]				
Coefficient of Thermal Expansion[g]				
13.0×10^{-6} in./in./F (70 to 212 F)				
Density[g]				
0.102 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle unless otherwise indicated. Values for fatigue, creep, and rupture are from curves generated using the results of a greater number of tests.
(b) Single-shear sheet-type specimens, full thickness.
(c) U - unavailable, NA - not applicable.
(d) Center-notched specimen, 3 x 12 inches. Pop-in was experienced at room temperature. Value given is average of six tests. Pop-in was not experienced at 250 F and tests proved to be invalid by secant-offset method.
(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle, that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.
(f) Three-point bend test. Alternate immersion in 3 1/2% NaCl.
(g) Values from Reference 2.

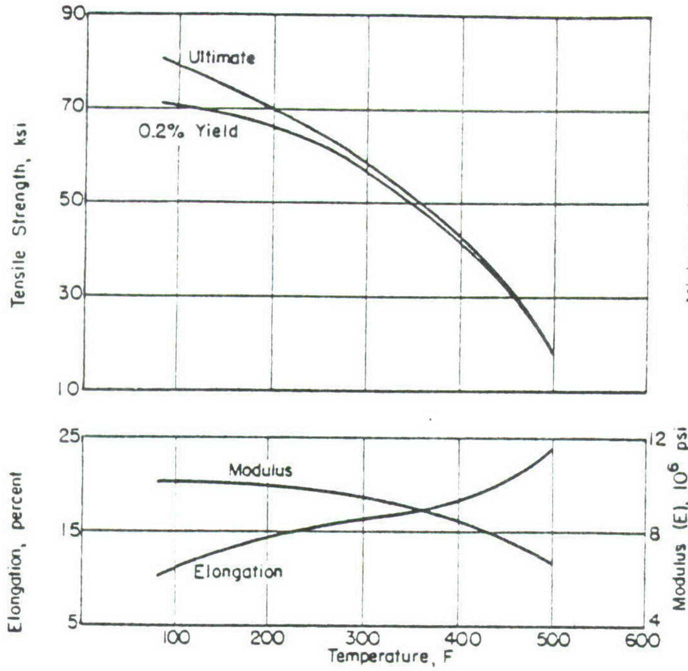


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7178-T76 ALUMINUM-ALLOY SHEET

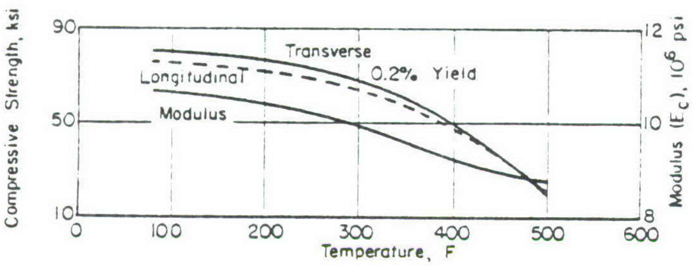


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7178-T76 ALUMINUM-ALLOY SHEET

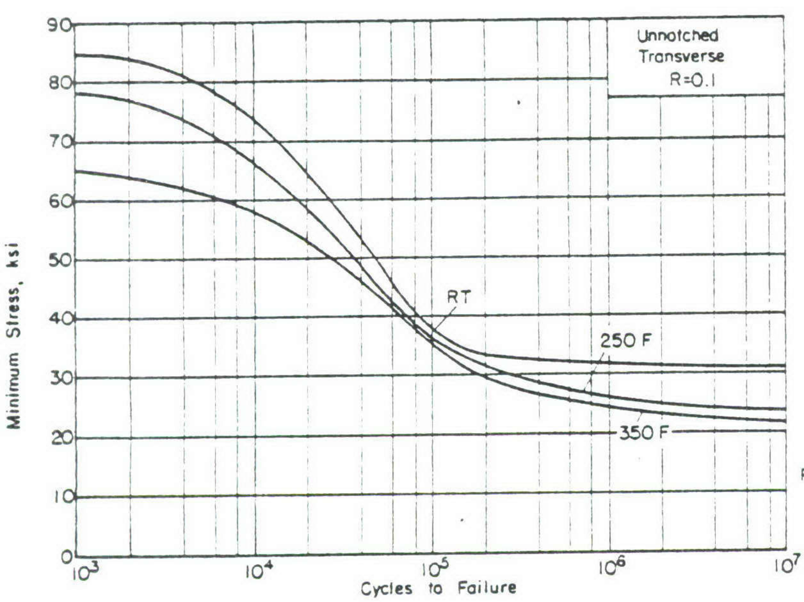


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 7178-T76 ALUMINUM SHEET AT THREE TEMPERATURES

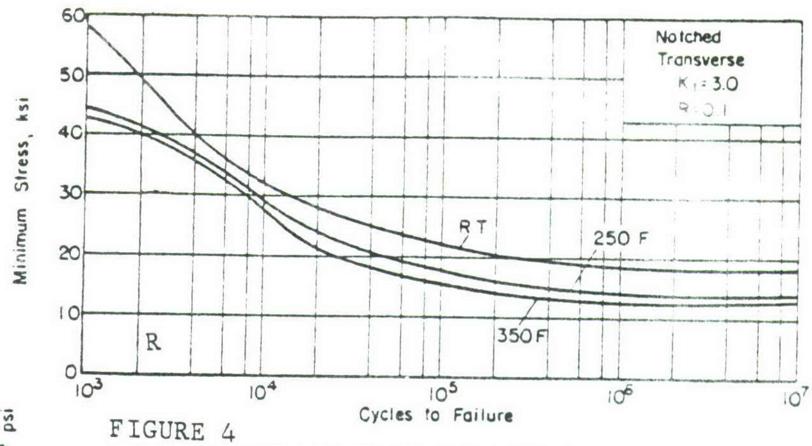


FIGURE 4
AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7178-T76 ALUMINUM SHEET AT THREE TEMPERATURES

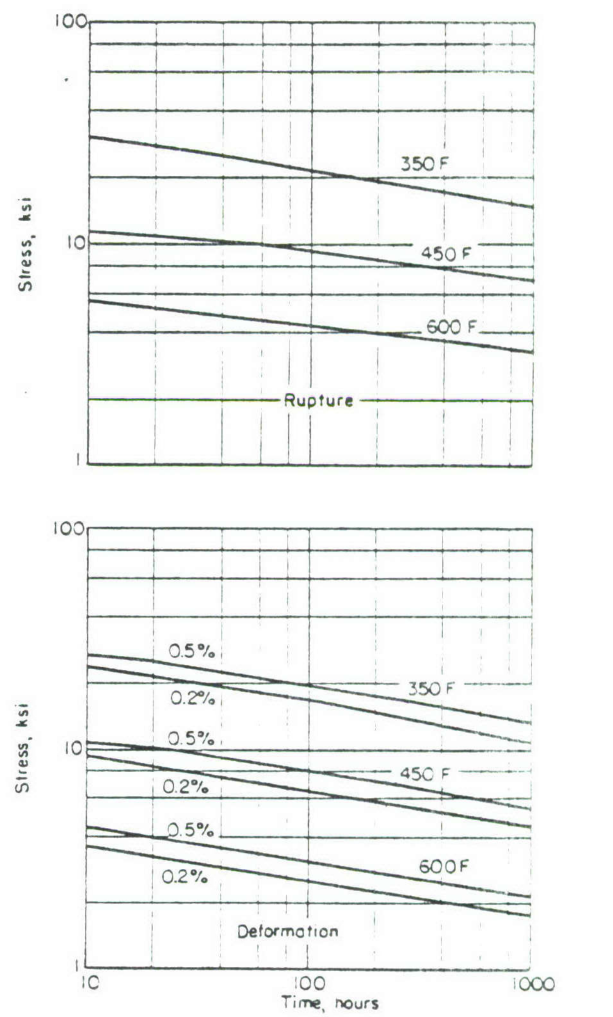


FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR 7178-T76 ALUMINUM-ALLOY SHEET

AF2-1DA

AF2-1DA is a newly developed high-temperature nickel-base alloy. It was developed by the Universal-Cyclops Specialty Steel Division under Air Force Contract AF 33(615)-1729. Further development and scale-up is being carried out under Contract F33615-67-C-1056. The intended usage of this material is for turbine wheel/bucket applications.

Nominal composition for AF2-1DA is 0.34 Cr, 12.0 Cr, 10.0 Co, 3.0 Mo, 6.0 W, 1.65 Ta, 4.50 Al, 3.0 Ti, 0.015 B, 0.14 Zr, balance nickel.

No fatigue data are presented in the data sheet. The quantity of usable material was limited and although fatigue tests were attempted, it is believed that the data obtained are not representative of the material's capabilities. If additional bar becomes available during the contract year the fatigue data will be added to this data sheet.

AF2-1DA DATA[a]

Condition: Aged
Thickness: 1-1/4-Inch Extruded Round Bar

Properties	Temperature, F			
	RT	1000	1400	1800
Tension				
F_{tu}, ksi	196.4	175.9	157.8	63.8
F_{ty}, ksi	149.0	147.5	143.9	48.1
e_t, percent in 2 in.	11.2	5.7	2.7	25.4
E_t, 10^6 psi	31.5	27.9	25.4	19.1
Compression				
F_{cy}, ksi	155.3	160.4	148.0	52.3
E_c, 10^6 psi	33.3	30.9	29.3	24.9
Shear				
F_{su}, ksi	135.0[b]	U[c]	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	U	U	U	U
Axial Fatigue				
Unnotched, R = 0.1	U	--	U	U
10^3 cycles, ksi	U	--	U	U
10^5 cycles, ksi	U	--	U	U
10^7 cycles, ksi	U	--	U	U
Notched (K_t = 4.0), R = 0.1				
10^3 cycles, ksi	U	--	U	U
10^5 cycles, ksi	U	--	U	U
10^7 cycles, ksi	U	--	U	U

Properties	Temperature, F 1400	1600	1800
Creep			
0.2% plastic deformation 100 hr, ksi	64.0	27.0	6.6
0.2% plastic deformation 1000 hr, ksi	54.0	16.5	3.3
Stress Rupture			
Rupture 100 hr, ksi	73.0	44.0	16.0
Rupture 1000 hr, ksi	68.0	30.0	9.5
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks(d)		
Coefficient of Thermal Expansion			
8.5×10^{-6} in./in./F (RT to 1200 F)			
Density 0.292 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Creep and stress rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen.

(c) U = unavailable.

(d) Room-temperature three-point bend test. No cracks appeared after alternate immersion in 3-1/2 percent NaCl for 1000 hours.

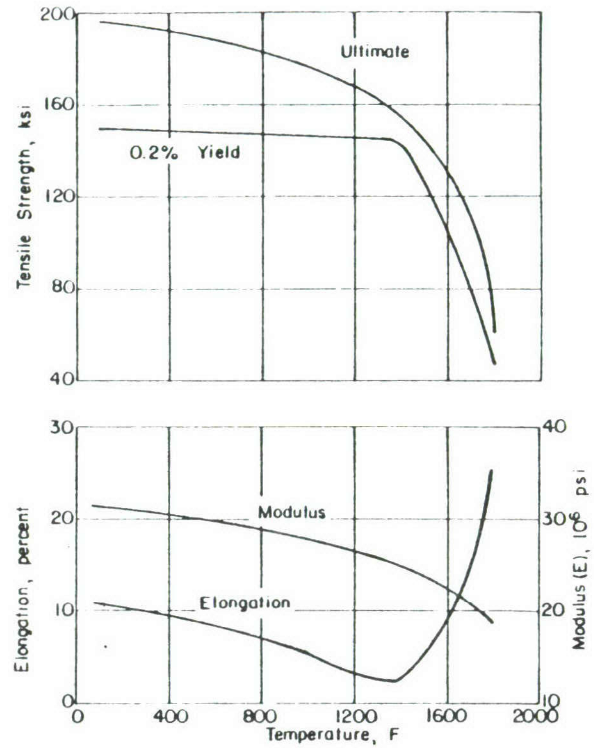


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF2-1DA EXTRUDED ROUND BAR

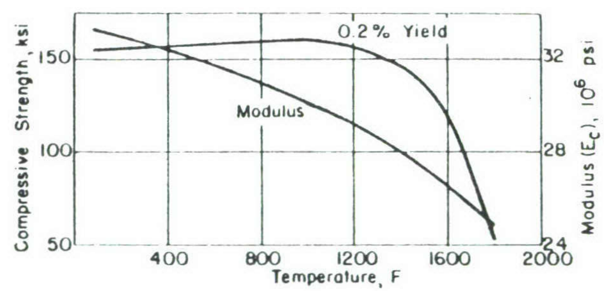


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF2-1DA EXTRUDED ROUND BAR

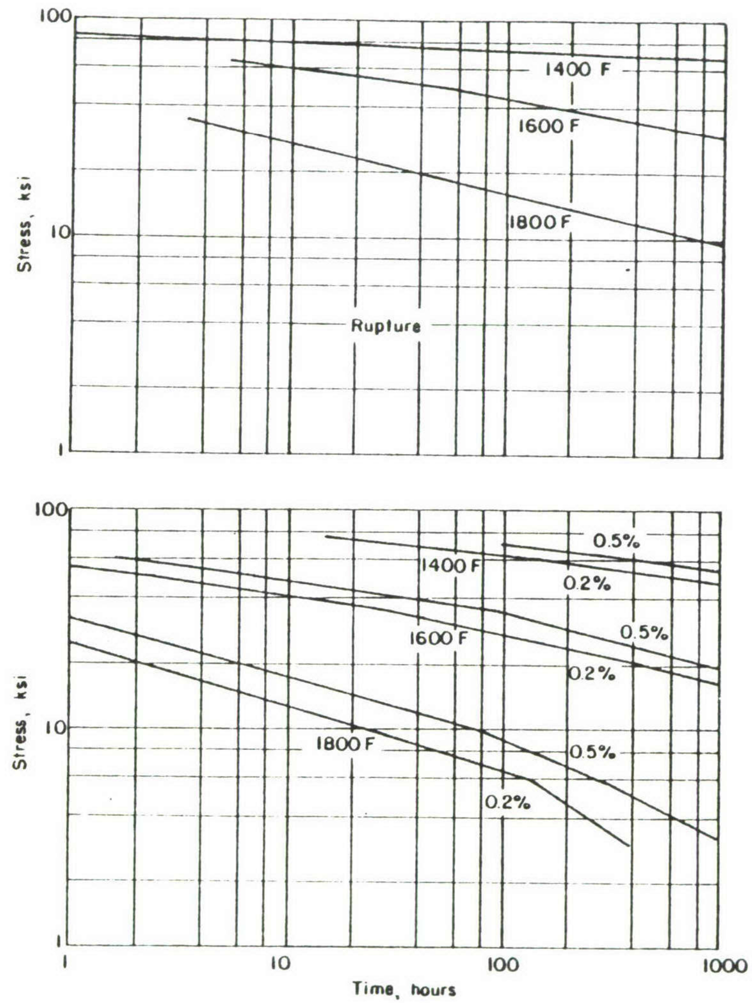


FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR AF2-IDA EXTRUDED ROUND BAR

MP35N Multiphase Alloy

MP35N is a new nickel-cobalt-chromium-molybdenum alloy developed by the E. I. duPont deNemours and Company, Incorporated. The rights to this alloy, MP35N, and the family of composition from which it was derived, MULTIPHASE[(T)] Alloys, were acquired by Standard Pressed Steel Company in 1967 and Latrobe Steel Company was subsequently licensed to manufacture the MULTIPHASE Alloys.

MP35N is hardened by work strengthening and aging to strength levels of 260 – 300 ksi. In addition to high strength and good ductility, the alloy is reported to have excellent resistance to corrosion and stress corrosion in salt water and other chloride solutions. Potential usage of this material is for fasteners, springs, marine drive shafts, cables, etc.

MP35N is available as ingot, billet, bar stock, wire, and tubing. A fabricator of flat-rolled products will be licensed soon so that all product forms will be available.

The composition of the 1-inch round bar stock used for this evaluation was as follows:

Ni – 35.24
Co – 35.11
Cr – 19.48
Mo – 9.61
C – 0.015

The material was work strengthened and aged at 1050 F for 4 hours and air cooled to attain a nominal strength level of 260 ksi.

(T) Trademark of the Standard Pressed Steel Company.

MP35N ALLOY DATA[(a)]

CONDITION: WORK-STRENGTHENED AND AGED
THICKNESS: 1-INCH DIAMETER ROUND BAR

Properties	Temperature, F			
	RT	400	700	1200
<u>Tension</u>				
F_{tu}, ksi	273.0	245.0	228.0	139.3
F_{tu}, Notched (K_t = 6.3), ksi	304.1	--	--	--
F_{tu}, Notched (K_t = 9.0), ksi	284.1	--	--	--
F_{ty}, ksi	263.0	238.3	221.0	155.0
e_t, percent in 2-in.	11.3	11.0	8.3	19.7
RA, percent	53.5	51.2	42.5	23.2
E_t, 10^6 psi	35.9	32.7	32.7	23.6
<u>Compression</u>				
F_{cy}, ksi	253.0	211.0	197.0	150.0
E_c, 10^6 psi	33.9	32.5	29.3	23.8
<u>Shear</u>				
F_{su}, ksi	144.7[(b)]	U[(c)]	U	U
<u>Impact</u> (v-notch charpy), ft-lb	24.0	20.5	14.6	U
<u>Fracture Toughness</u>, K_{Ic}[(d)]	78.7	U	U	U
<u>Axial Fatigue</u>[(e)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	273	264	258	U
10^5 cycles, ksi	194	184	180	U
10^7 cycles, ksi	157	140	134	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	204	188	170	U
10^5 cycles, ksi	80	74	68	U
10^7 cycles, ksi	45	50	60	U

Properties	RT	700	900	1200
	Temperature, F			
Creep				
	NA	222	130	35
	NA	221	103	25
Stress Rupture				
	NA	223	212	97
	NA	222	209	75

Stress Corrosion

80% F_{ty}, 1000 hrs. Max. No Cracks(f)

Coefficient of Thermal Expansion

10^{-6} in/in/F 7.1 (70-200 F)

8.2 (70-600 F)

8.7 (70-1000 F)

Density

0.304 lb/in^3

(a) Data are average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Average of 4 slow-bend tests.

(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) 3-point bend test. Alternate immersion 3-1/2 percent NaCl.

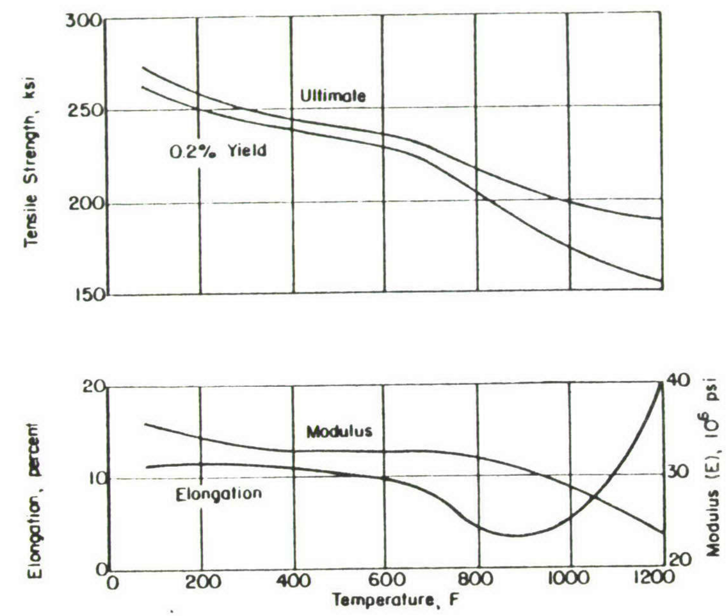


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF MP35N MULTIPHASE ALLOY BAR

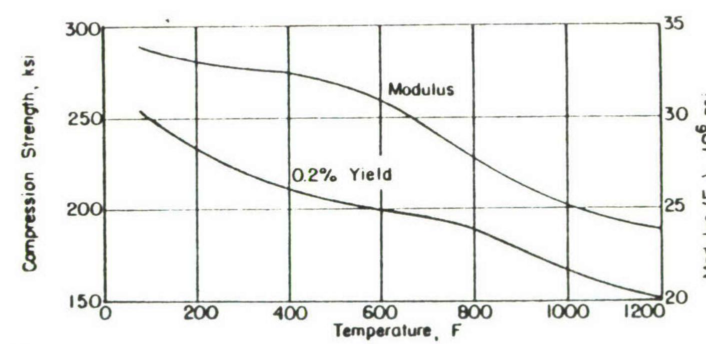


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF MP35N MULTIPHASE ALLOY BAR

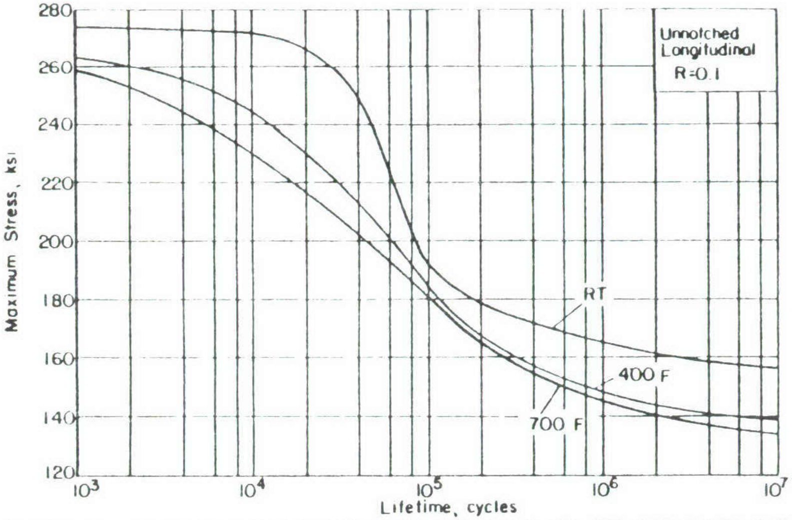


FIGURE 3 AXIAL LOAD FATIGUE RESULTS FOR MP35N MULTIPHASE ALLOY BAR AT THREE TEMPERATURES

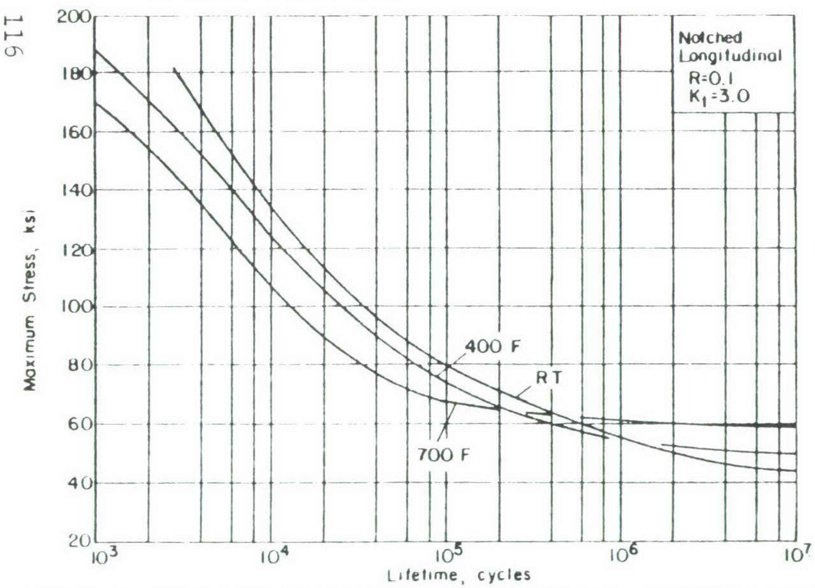


FIGURE 4 AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) MP35N MULTIPHASE ALLOY BAR AT THREE TEMPERATURES

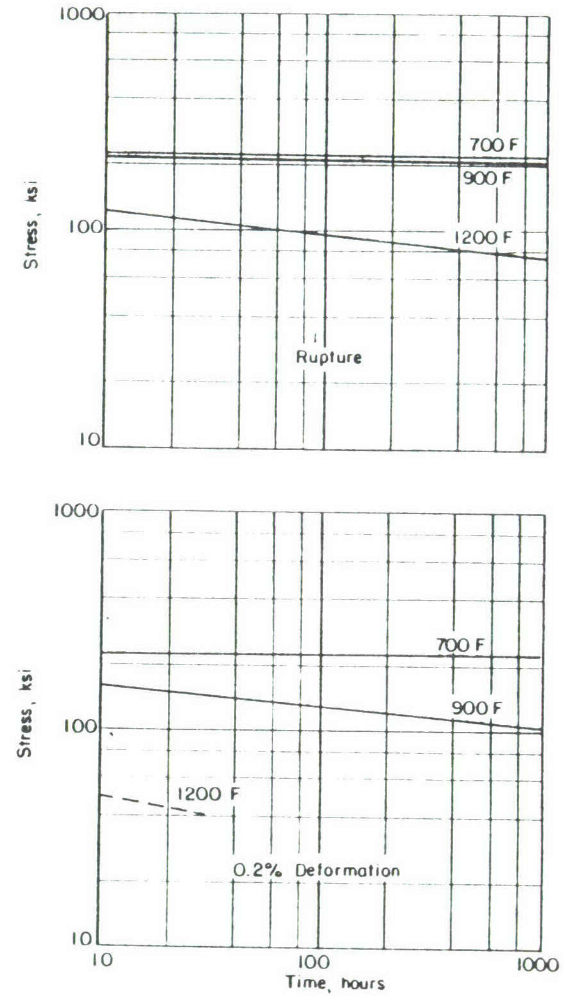


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR MP35N MULTIPHASE ALLOY BAR

RMI 38-6-44 TITANIUM ALLOY

38-6-44 alloy (3Al-8V-6Cr-4Mo-4Zr) is a new deep-hardening beta composition alloy developed by Reactive Metal, Incorporated. The large amount of beta stabilizing elements in this composition results in sluggish transformation characteristics which give deep hardening. The metallurgy of 38-6-44 alloy is similar to other beta alloys such that solution annealing retains the more ductile body-center-cubic beta phase at room temperature.

The 6-inch by 6-inch billet used in this property survey was solution annealed at 1500 F for 15 minutes and air cooled, plus aging at 1050 F for four hours.

RMI 38-6-44 TITANIUM ALLOY[a]

Condition: STA
Thickness: 6 x 6 Forging

Properties	Temperature, F			
	RT	400	700	900
Tension				
F_{tu} (longitudinal), ksi	177.0	166.0	159.0	140.0
F_{tu} (transverse), ksi	168.0	164.0	155.0	140.0
F_{ty} (longitudinal), ksi	167.0	148.0	139.0	123.0
F_{ty} (transverse), ksi	167.0	146.3	135.0	125.0
e (longitudinal), percent in 2 in.	10.0	7.7	8.7	33.5
e (transverse), percent in 2 in.	6.0	5.0	6.0	17.3
RA (longitudinal), percent	18.2	13.5	15.6	76.0
RA (transverse), percent	10.9	8.9	11.9	42.5
E (longitudinal), 10^6 psi	15.4	13.8	12.3	11.6
E (transverse), 10^6 psi	15.1	14.6	13.0	11.8
Compression				
F_{cy} (longitudinal), ksi	161.0	140.0	130.0	113.3
F_{cy} (transverse), ksi	155.0	137.0	129.0	116.0
E_c (longitudinal), 10^6 psi	14.8	13.5	12.4	11.2
E_c (transverse), 10^6 psi	14.7	13.7	11.9	11.4
Shear[b]				
F_{su} (longitudinal), ksi	119.5	U[c]	U	U
F_{su} (transverse), ksi	119.0	U	U	U
Impact (V-notch charpy)[d]				
Energy (longitudinal), ft-lb	7.5	U	U	U
Energy (transverse), ft-lb	5.0	U	U	U
Fracture Toughness, K_{IC}, ksi $\sqrt{in.}$				
Near outside of forging	57.7	U	U	U
Near center of forging	60.1	U	U	U
Fatigue (Transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	166.0	158.0	148.0	U
10^5 cycles, ksi	124.0	106.0	92.0	U
10^7 cycles, ksi	87.0	80.0	64.0	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	120.0	104.0	92.0	U
10^5 cycles, ksi	44.0	36.0	40.0	U
10^7 cycles, ksi	40.0	30.0	34.0	U

Properties	RT	Temperature, F 400	700	900
Creep (Transverse)				
0.2% plastic deformation, 100 hr	NA	141.0	58.0	5.4
0.2% plastic deformation, 1000 hr	NA	140.0	25.0	2.5
Stress Rupture (Transverse)				
Rupture, 100 hr	NA	143.0	137.0	50.0
Rupture, 1000 hr	NA	142.0	133.0	31.0
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks(g)			
Coefficient of Thermal Expansion				
5.38×10^{-6} in./in./F (68-900 F)				
Density				
0.174 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Longitudinal 7.5 at 132 F
Transverse 5.7 at 132 F

(e) Each value is average of 4 slow-bend tests.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle, that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Room temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

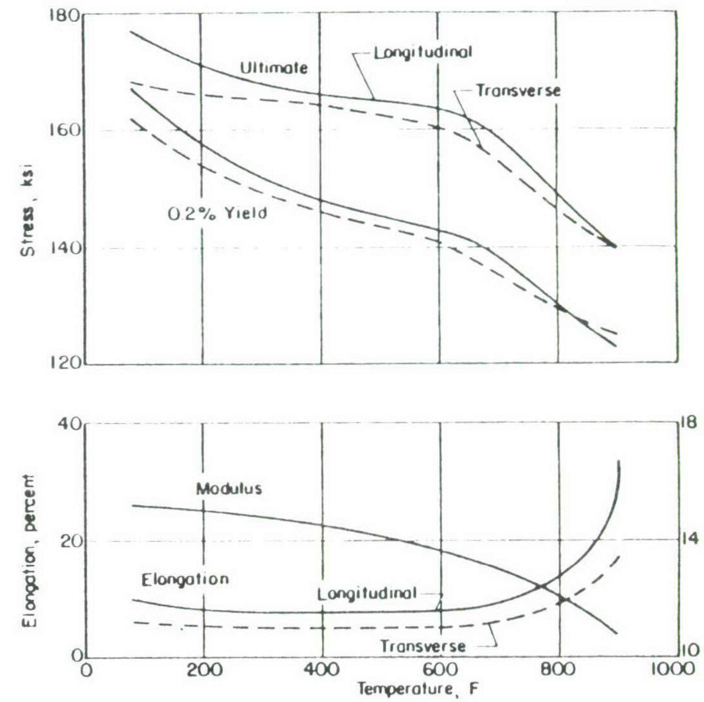


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

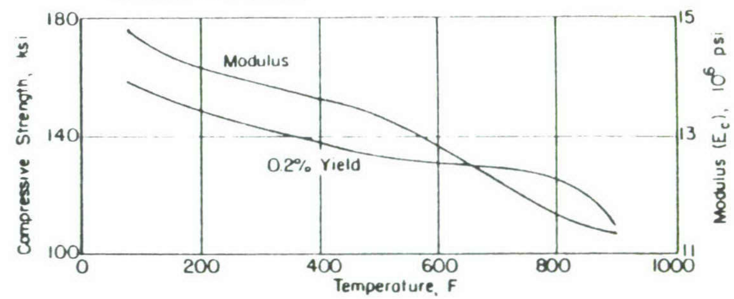


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

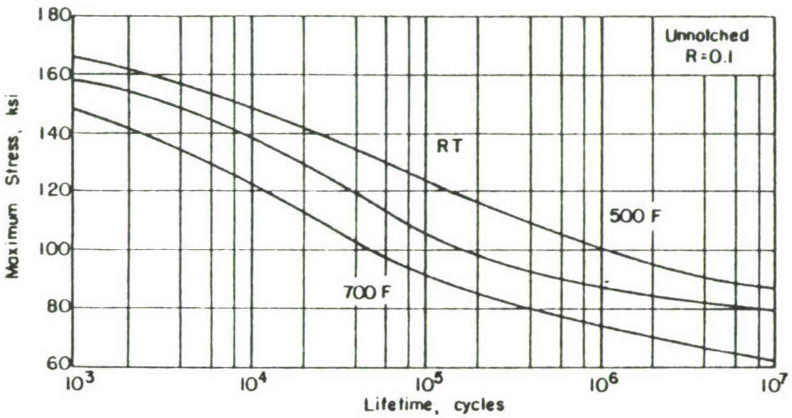


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 38-6-44 TITANIUM FORGINGS

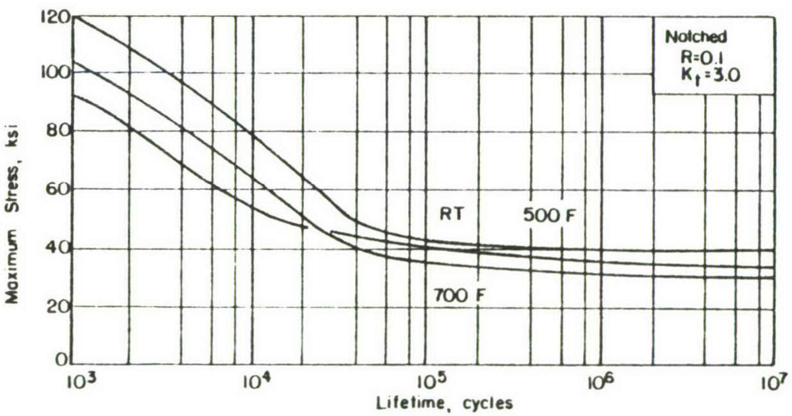


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 38-6-44 TITANIUM FORGINGS

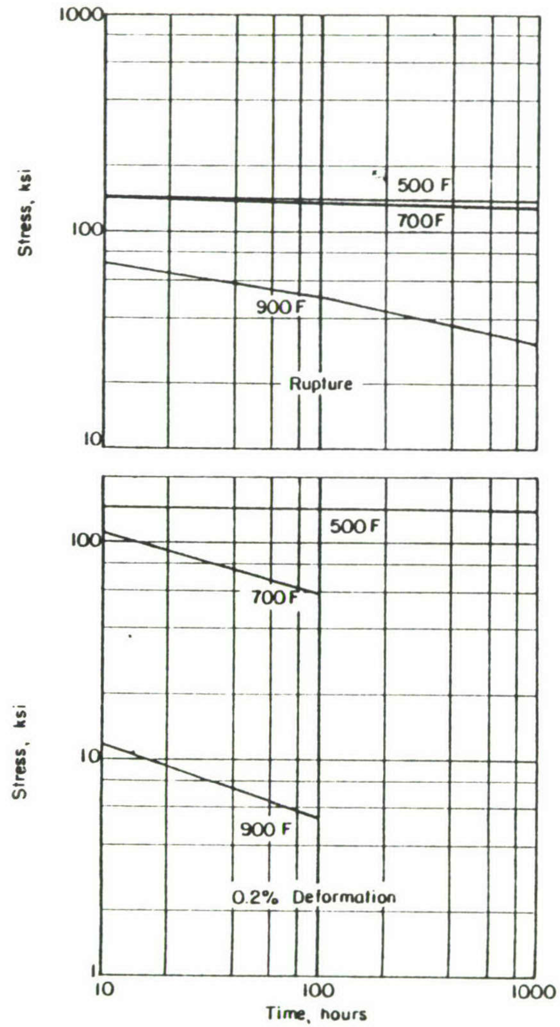


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 38-6-44 TITANIUM FORGINGS

7175 Aluminum Alloy

7175 is a new Premium Strength Die Forging developed by Alcoa. This development is intended to provide relatively high strength/weight ratios for aerospace applications. The guaranteed minimum longitudinal yield strength for the -T736 temper is approximately 17 percent above the current minimum requirements of specifications covering 7075 alloy die forgings in the -T73 temper. Although the development emphasis was placed on high longitudinal strength, the transverse ductility is also well above that of most conventional 7075 die forgings.

Tests on a limited number of forgings (by Alcoa) in the -T736 temper indicate that the stress-corrosion cracking threshold in the short transverse direction should be at least 35 ksi.

Currently, the product is limited to closed die airframe-type forgings.

7175 Aluminum[(a)]
Condition: -T736
Thickness: Various (Die Forging)

Properties	Temperature, F			
	RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	82.0	66.3	52.8	19.7
F_{tu} (transverse), ksi	79.2	64.2	50.7	19.2
F_{ty} (longitudinal), ksi	75.4	66.2	52.6	19.7
F_{ty} (transverse), ksi	72.3	64.0	50.4	19.2
e_t (longitudinal), percent in 2 in.	14.3	21.0	23.3	29.0
e_t (transverse), percent in 2 in.	12.3	16.0	21.0	26.3
RA (longitudinal), percent	36.8	52.8	67.0	91.5
RA (transverse), percent	35.8	47.2	62.9	91.0
E_t (longitudinal), 10^6 psi	10.3	9.7	8.6	8.2
E_t (transverse), 10^6 psi	10.0	9.5	8.5	8.3
Compression				
F_{cy} (longitudinal), ksi	78.8	69.8	57.1	22.2
F_{cy} (transverse), ksi	74.0	65.5	54.8	21.8
E_c (longitudinal), 10^6 psi	11.0	10.1	8.9	8.0
E_c (transverse), 10^6 psi	10.7	9.9	9.3	7.6
Shear[(b)]				
F_{su} (longitudinal), ksi	47.5	U[(c)]	U	U
F_{su} (transverse), ksi	49.7	U	U	U
Impact (V-Notch Charpy)				
Energy (longitudinal), ft-lb	6.2[(d)]	U	U	U
Energy (transverse), ft-lb	5.3	U	U	U
Fracture Toughness, K_{Ic}, ksi$\sqrt{in}$	48.5[(e)]	U	U	U

Properties	Temperature, F			
	RT	250	350	500
<u>Fatigue (longitudinal)</u>(f)				
Unnotched, R = 0.1				
10^5 cycles, ksi	82	80	68	U
10^6 cycles, ksi	63	58	50	U
10^7 cycles, ksi	34	33	28	U
Notched (K_t = 3.0), R = 0.1				
10^5 cycles, ksi	58	50	47	U
10^6 cycles, ksi	27	24	22	U
10^7 cycles, ksi	15	14	13	U
<u>Creep (longitudinal)</u>				
0.2% plastic deformation, 100 hr	NA	45	18	4.5
0.2% plastic deformation, 1000 hr	NA	40	12	3.0
<u>Stress Rupture</u>				
Rupture 100 hr	NA	51	23	6.5
Rupture 1000 hr	NA	44	15.5	4.7
<u>Stress Corrosion</u>				
80% F_{ty}, 1000 hr max	No cracks(g)			
<u>Coefficient of Thermal Expansion</u>				
12.5 x 10^{-6} in/in/F (68 – 250 F)				
<u>Density</u> 0.101 lb/in^3				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250-inch diameter.

(c) U, unavailable; NA, not applicable

(d) Longitudinal at -100 F = 4.5
Transverse at -100 F = 4.0
Longitudinal at -320 F = 4.5
Transverse at -320 F = 3.5
Each value is average of three tests at temperature indicated.

(e) Average of six slow bend tests.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Room temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

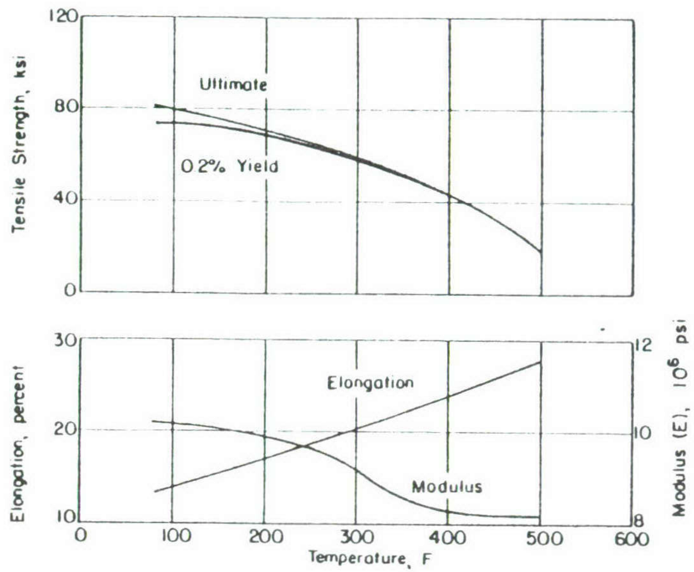


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T736 DIE FORGING

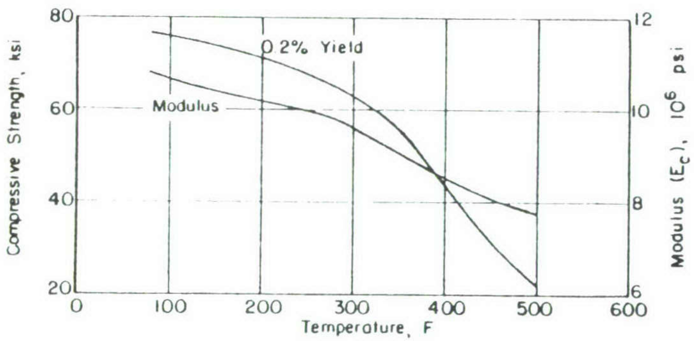


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T736 DIE FORGING

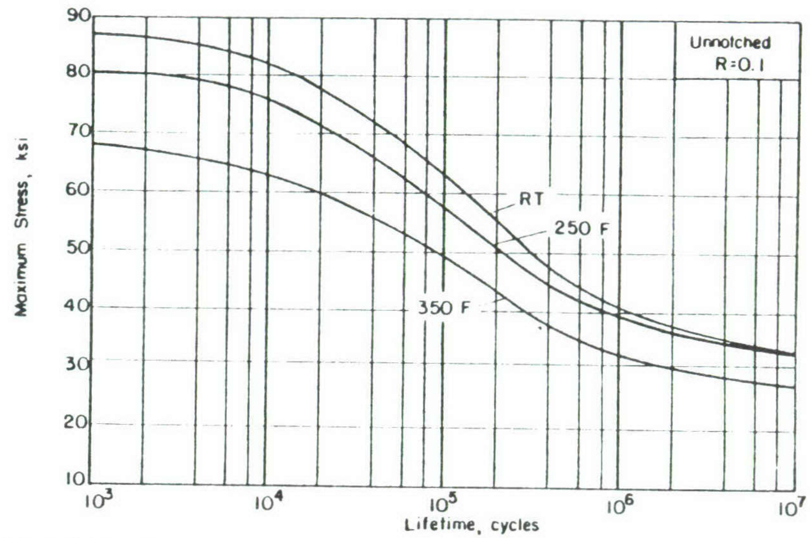


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 7175-T736 DIE FORGINGS AT THREE TEMPERATURES

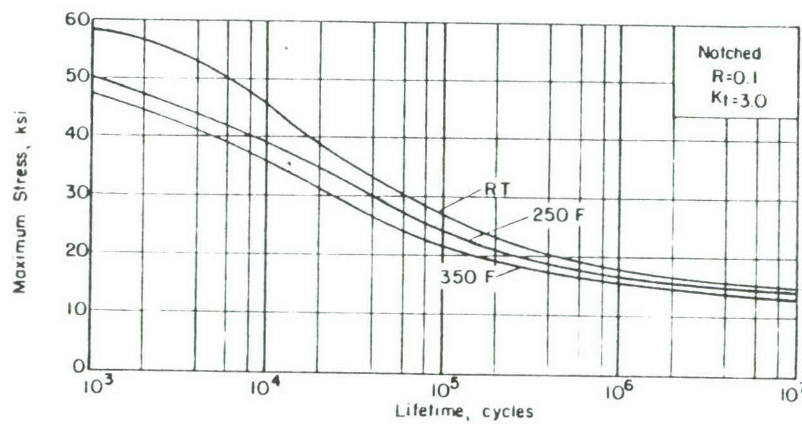


FIGURE 4. AXIAL LOAD LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7175-T736 DIE FORGINGS AT THREE TEMPERATURES

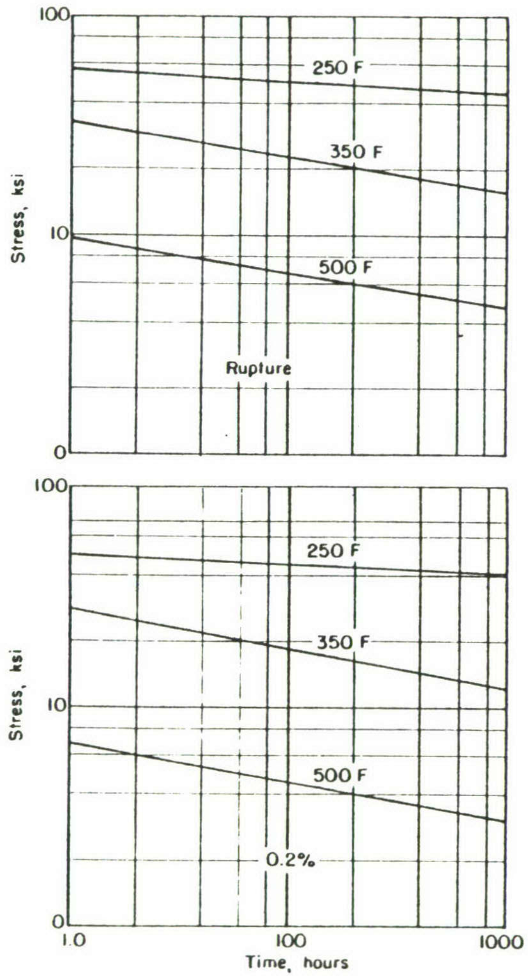


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7175-T736 DIE FORGINGS

5621-S Titanium Alloy

5621-S alloy is a new high-temperature titanium alloy developed by Reactive Metals, Incorporated. The alloy was developed to meet the need for a titanium alloy capable of withstanding temperatures as high as 1000 F for long periods. 5621-S contains silicon which enhances high temperature creep strength. This alpha-matrix alloy is reported to have moderate room temperature tensile strength, excellent notch toughness, fatigue and creep strength, hot salt stress corrosion resistance, and thermal stability. It is reported to have greater creep strength than any other commercially available titanium alloy.

Currently all mill product forms have been manufactured, and bar and billet are available from RMI. Sheet and plate are undergoing investigation and are expected to be commercially available in the near future.

The nominal chemical composition of 5621-S is as follows:

Al	4.50-5.50
Sn	5.00-7.00
Zr	1.50-2.50
Mo	0.50-1.00
Si	0.15-0.35
Fe	0.30 Maximum
C	0.05 Maximum
O	0.15 Maximum
N	0.03 Maximum
H	0.0125
Others	0.40 Total

Balance Titanium

Ti-5621-S[(a)]
Condition: STA
Thickness: 1-1/2-inch Pancake Forging

Properties	Temperature, F			
	RT	400	700	900
Tension				
F_{tu} (Radial), ksi	139.6	116.0	103.3	98.1
F_{tu} (Tangential), ksi	136.3	114.3	105.0	97.9
F_{ty} (Radial), ksi	119.0	88.5	74.3	71.2
F_{ty} (Tangential), ksi	117.3	88.3	77.2	71.5
e_t (Radial), percent in 2 in.	13.6	16.7	18.2	19.0
e_t (Tangential), percent in 2 in.	11.3	15.0	15.0	16.2
RA (Radial), percent	20.4	27.2	30.4	37.0
RA (Tangential), percent	19.2	29.1	31.6	32.3
E_t (Radial), 10^3 psi	17.2	16.9	15.1	14.3
E_t (Tangential), 10^3 psi	17.1	16.6	14.8	14.2
Compression				
F_{cy} (Radial), ksi	133.0	95.4	77.5	74.3
F_{cy} (Tangential), ksi	135.3	96.2	78.0	76.9
E_c (Radial), 10^3 psi	17.5	16.4	14.8	14.1
E_c (Tangential), 10^3 psi	17.5	15.9	14.9	14.3
Shear[(b)]				
F_{su} (Radial), ksi	99.3	U[(d)]	U	U
F_{su} (Tangential), ksi	94.9	U	U	U
Impact (V-Notch Charpy), ft-lb	21.3[(c)]	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	76.5[(e)]	U	U	U

Properties	Temperature, F RT	400	700	900
Fatigue (Radial)[(f)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	150	140	124	U
10^5 cycles, ksi	114	110	103	U
10^7 cycles, ksi	85	82	78*	U
Notched (K_t = 3.0) R = 0.1				
10^3 cycles, ksi	110	106	100	U
10^5 cycles, ksi	54	49	44	U
10^7 cycles, ksi	38	38	38	U
Creep (Radial)	RT	600	800	950
0.2% plastic deformation, 100 hr	NA	107	91	71
0.2% plastic deformation, 1000 hr	NA	106	90	60
Stress Rupture (Radial)				
Rupture 100 hr	NA	108	91.5	86
Rupture 1000 hr	NA	107	91	79
Stress Corrosion				
80% F_{ty}, 1000 hr max	No Cracks[(g)]			
Coefficient of Thermal Expansion				
5.36 x 10^{-6} in./in./F(68 – 700 F)				
Density 0.163 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.
(b) Double-shear pin-type test, 0.250-inch specimen.
(c) 21.3 at RT, 17.2 at -40 F, 14.0 at -100 F.
(d) U, unavailable, NA, not applicable.
(e) Average of five slow-bend tests, tests at 400 F were marginal by the established criteria and are not reported.
(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle, that is $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.
(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

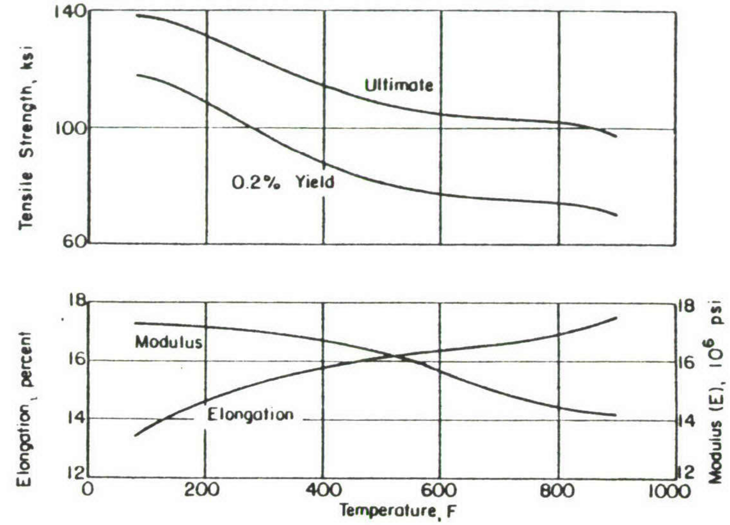


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-5621S PANCAKE FORGING

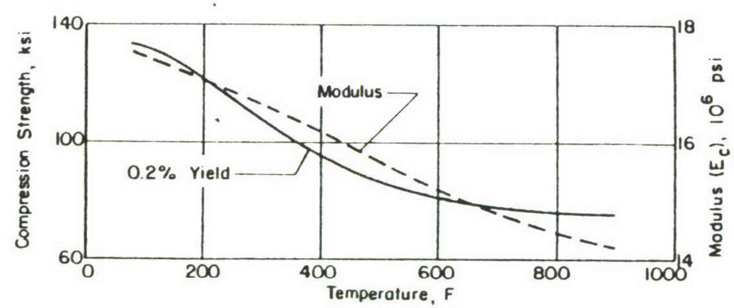


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF Ti-5621S PANCAKE FORGING

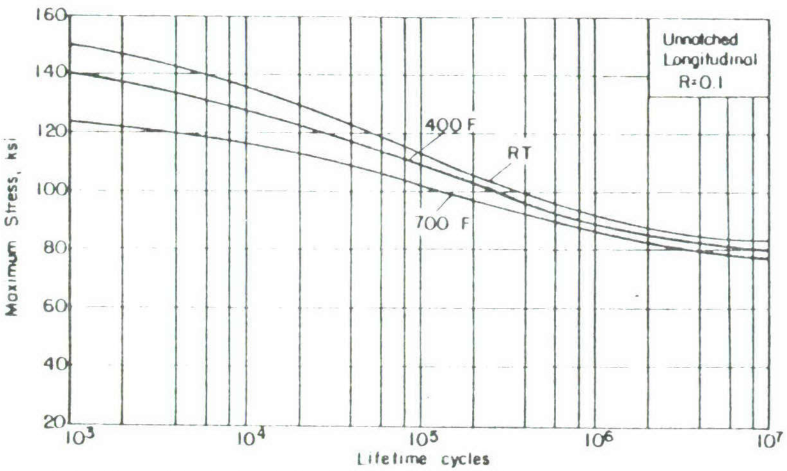


FIGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR Ti-5621S PANCAKE FORGING AT THREE TEMPERATURES

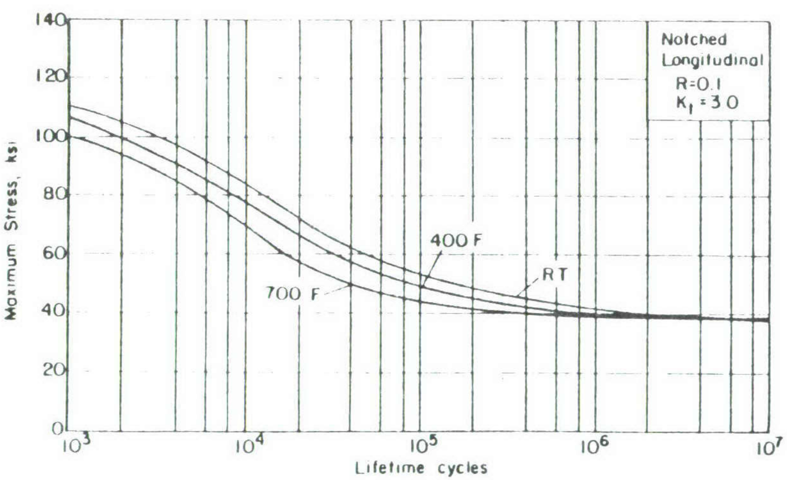


FIGURE 4 AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) Ti-5621S PANCAKE FORGING AT THREE TEMPERATURES

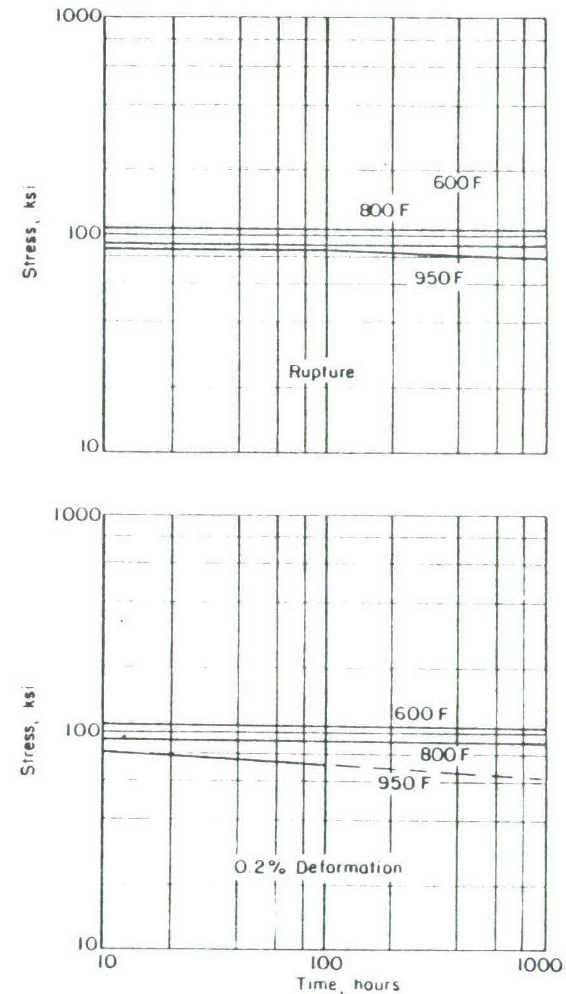


FIGURE 5 STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR Ti-5621S PANCAKE FORGING

Inconel 625 Alloy

Inconel 625 is a relatively new product of Huntington Alloy Products Division of The International Nickel Company, Inc. It is reported to have high strength and toughness from cryogenic temperatures to 2000 F. It is a nonmagnetic alloy deriving its strength from the stiffening effect of molybdenum and columbium on its nickel-chromium matrix. It has good oxidation resistance and is virtually immune to chloride-ion stress-corrosion cracking.

Inconel 625 is readily fabricated by common industrial practices and has excellent weld qualities, requiring no postweld thermal treatment for maintenance of its corrosion resistance. The alloy has already been used in numerous aerospace applications and is currently being evaluated for use in the chemical and marine fields.

Standard mill forms including sheet, strip, rods and bars, shapes, tube and plate are available.

The nominal composition of Inconel 625 is as follows.

C	Mn	Fe	S	Si	Cr	Al	Ti
0.10	0.50	5.0	0.015	0.50	20.0-23.0	0.40	0.40

Mo	Co	P	Cb + Ta	Ni
8.0-10.0	1.0 max	0.015	3.5-4.15	Balance

Inconel 625 Data[(a)]

Condition: Annealed
Thickness: 0.125-inch sheet

Properties	RT	Temperature, F 800	1200	1600
Tension				
TUS (longitudinal), ksi	138.7	123.3	112.3	29.8
TUS (transverse), ksi	136.7	122.3	113.0	29.3
TYS (longitudinal), ksi	69.5	53.3	48.9	29.7
TYS (transverse), ksi	69.6	53.6	49.6	29.0
e_t (longitudinal), percent in 2 in.	51.1	50.0	97.0	123.0
e_t (transverse), percent in 2 in.	50.0	51.0	81.3	118.0
E_t (longitudinal), 10^6 psi	28.3	24.1	22.5	14.6
E_t (transverse), 10^6 psi	30.3	25.0	24.7	18.1
Compression				
CYS (longitudinal), ksi	71.5	57.5	55.6	31.5
CYS (transverse), ksi	73.4	59.0	54.9	31.4
E_c (longitudinal), 10^6 psi	29.1	24.0	24.8	15.5
E_c (transverse), 10^6 psi	30.7	26.2	25.2	14.2
Shear[(b)]				
SUS (longitudinal), ksi	114.5	U[(e)]	U	U
SUS (transverse), ksi	115.8	U	U	U
Bend[(c)]				
Longitudinal, minimum radius	T/5	U	U	U
Transverse, minimum radius	T/5	U	U	U
Fracture Toughness, K_c[(d)]				
ksi$\sqrt{\text{in.}}$	(d)	U	U	U
Axial Fatigue (transverse)[(f)]				
Unnotched, R = 0				
10^3 cycles, ksi	140	120	100	U
10^5 cycles, ksi	106	102	78	U
10^7 cycles, ksi	72	96	68	U
Notched, K_t = 3.0, R - 0.1				
10^3 cycles, ksi	130	114	80	U
10^5 cycles, ksi	60	52	48	U
10^7 cycles, ksi	40	40	40	U
Creep (transverse)				
0.2% plastic deformation, 100 hr	NA	(h)	58	1.4
0.2% plastic deformation, 1000 hr	NA	(h)	50	0.8

Inconel 625 Data (continued)

Properties	RT	Temperature, F 800	1200	1600
Stress Rupture (transverse)				
Rupture, 100 hr	NA	>120	72	59
Rupture, 1000 hr	NA	>120	7	3.5
Stress Corrosion				
80% TYS, 1000-hr maximum	No cracks(g)			
Coefficient of Thermal Expansion				
7.4×10^{-6} in./in./F (70 to 500 F)				
8.7×10^{-6} in./in./F (70 to 1500 F)				
Density				
0.305 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Single-shear sheet-type specimen.

(c) Specimens tested at RT, +32 F, and -90 F. No cracks at either temperature.

(d) Specimens were full sheet thickness x 18 in. x 48 in. with EDM flaw in center. Average K_c was 158 ksi$\sqrt{\text{in.}}$ The net section yield stress at fracture was greater than the tensile yield strength of the material; therefore, the K values are considered not valid.

(e) U, unavailable; NA, not applicable.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

(h) Extensometer inoperative due to large initial strain; negative creep occurred.

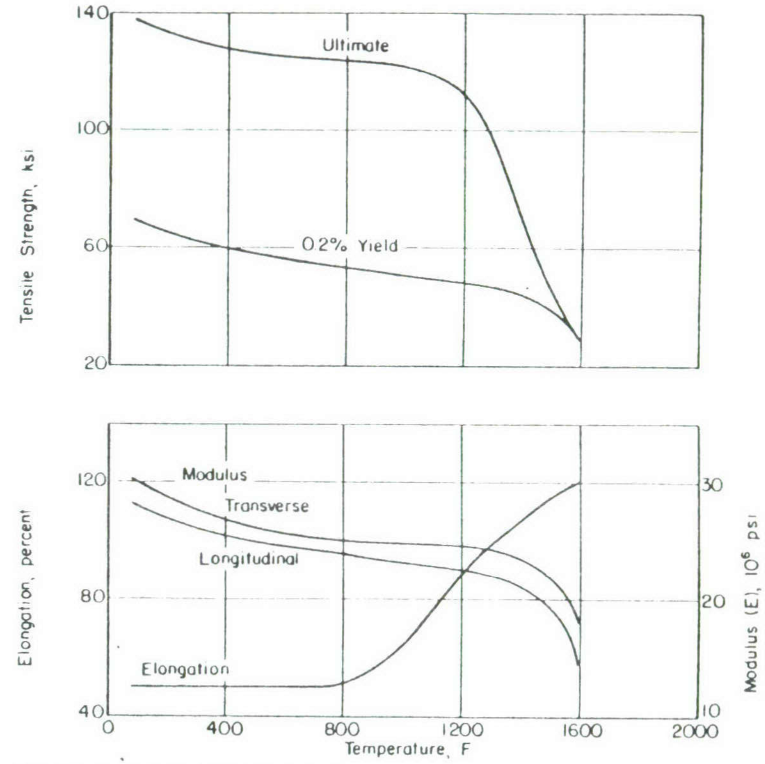


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF INCONEL 625 SHEET

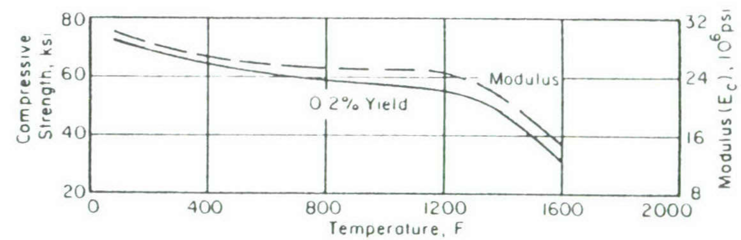


FIGURE 2 EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF INCONEL 625 SHEET

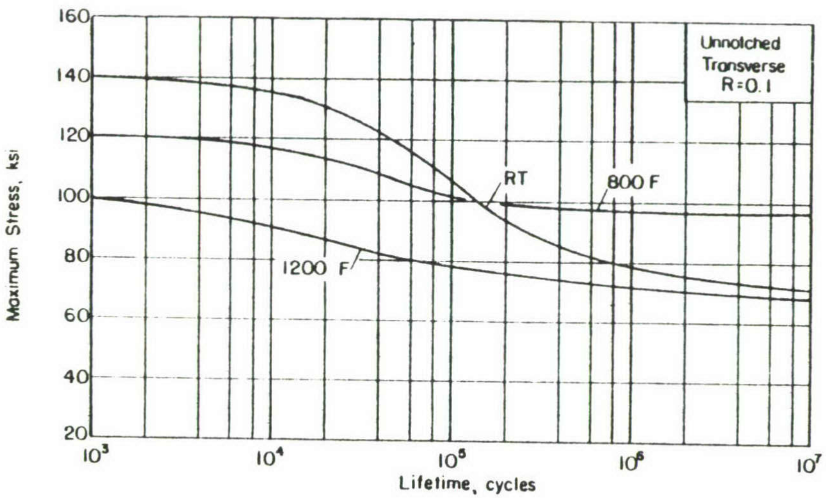


FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR INCONEL 625 SHEET

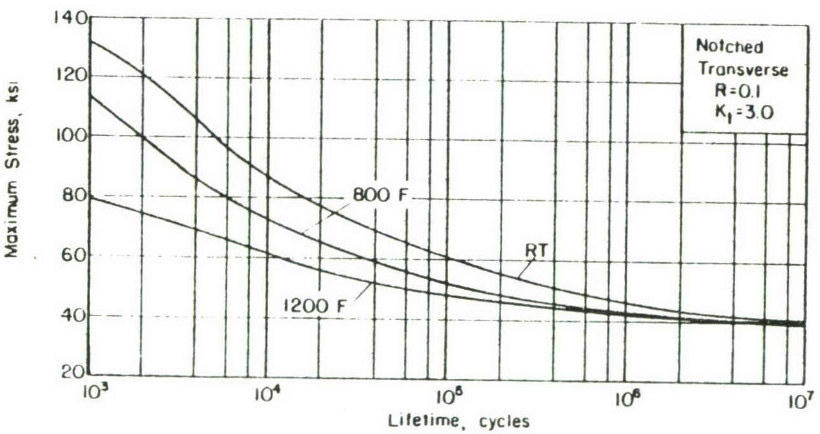


FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) INCONEL 625 SHEET

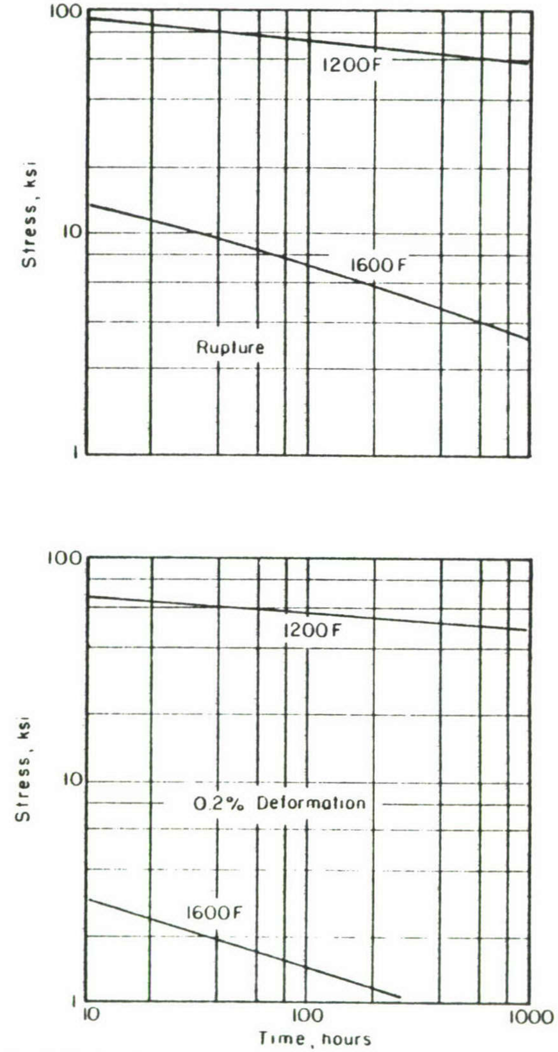


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR INCONEL 625 SHEET

AF2-1DA Alloy

AF2-1DA is a recently developed high-temperature nickel-base alloy. It was developed by the Universal-Cyclops Specialty Steel Division under Air Force Contract AF 33(615)-1729. Early development was in thick section form for turbine wheel/bucket applications. A "data sheet" for extruded material was issued under an earlier contract (F33615-69-C-1115).

A sheet manufacturing process for AF2-1DA alloy was developed at Union Carbide, also under Air Force sponsorship (Contract AF 33(615)-3883). The sheet material evaluated and reported herein was supplied by the Air Force from this program. The heat-treatment used for the material was 2225F/2 hrs/RAC + 1950F/2 hrs/AC + 1400F/16 hrs/AC. The composition of the material was as follows:

Carbon	0.32
Molybdenum	2.98
Zirconium	0.10
Tantalum	1.60
Tungsten	5.79
Cobalt	9.68
Chromium	12.18
Aluminum	4.36
Titanium	3.16
Boron	.014
Nickel	Balance

AF2-1DA Data[(a)]

Condition: STA
Thickness: 0.060-inch sheet

Properties	Temperature, F RT	1000	1400	1800
Tension				
TUS (longitudinal), ksi	191.7	153.0	130.0	46.4
TUS (transverse), ksi	180.0	151.7	131.3	48.2
TYS (longitudinal), ksi	144.3	137.3	130.0	37.4
TYS (transverse), ksi	142.3	137.0	130.0	40.2
e_t (longitudinal), percent in 2 in.	12.0	2.3	0.8	7.8
e_t (transverse), percent in 2 in.	12.0	1.8	1.0	5.2
E_t (longitudinal), 10^6 psi	31.9	28.1	24.3	18.2
E_t (transverse), 10^6 psi	30.8	28.2	24.0	18.7
Compression				
CYS (longitudinal), ksi	153.0	143.0	136.0	35.5
CYS (transverse), ksi	153.0	143.3	132.0	38.9
E_c (longitudinal), 10^6 psi	31.3	34.3	25.8	17.6
E_c (transverse), 10^6 psi	32.4	29.6	26.4	18.2
Shear[(b)]				
SUS (longitudinal), ksi	120.5	U[(c)]	U	U
SUS (transverse), ksi	120.0	U	U	U
Fracture Toughness, K_c[(d)]				
ksi$\sqrt{\text{in.}}$	(d)	U	U	U
Axial Fatigue (transverse)[(e)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	190	160	80	U
10^5 cycles, ksi	115	108	58	U
10^7 cycles, ksi	60	74	36	U
Notched, K_t = 3.0, R = 0.1)				
10^3 cycles, ksi	150	106	64	U
10^5 cycles, ksi	54	43	34	U
10^7 cycles, ksi	30	36	24	U
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	108	43	2.9
0.2% plastic deformation, 1000 hr, ksi	NA	106	20	2.1

AF2-1DA Data (continued)

Properties	RT	Temperature, F 1000	1400	1800
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	110	65	9
Rupture, 1000 hr., ksi	NA	109	40	4.5
Stress Corrosion				
80% TYS, 1000-hr maximum	No cracks(f)	U	U	U
Coefficient of Thermal Expansion				
8.5×10^{-6} in./in./F (68 to 1200 F)				
Density				
0.292 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Single-shear sheet-type specimen.

(c) U, unavailable; NA, not applicable.

(d) GFM material quantity not sufficient for K_c tests.

(e) "R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

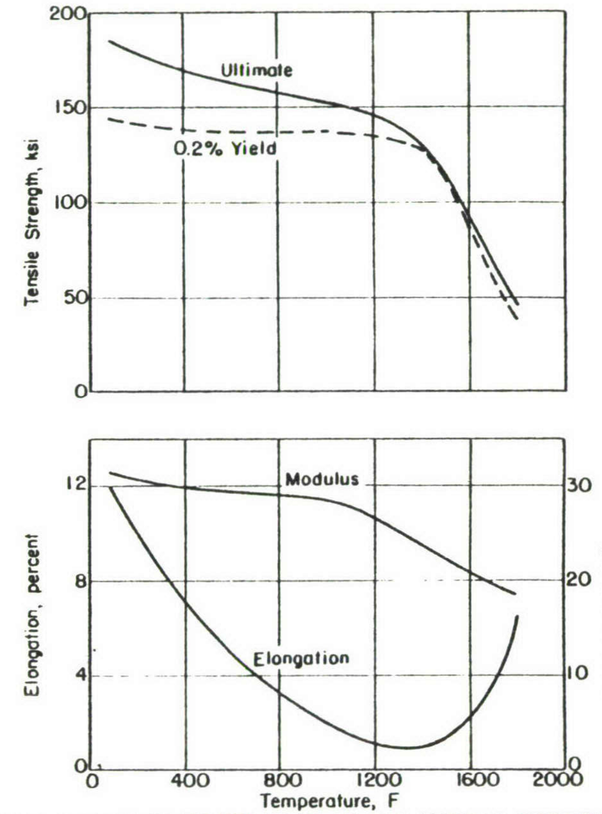


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF2-IDA SHEET

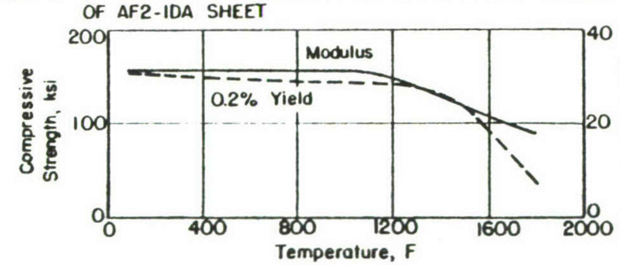


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF2-IDA SHEET

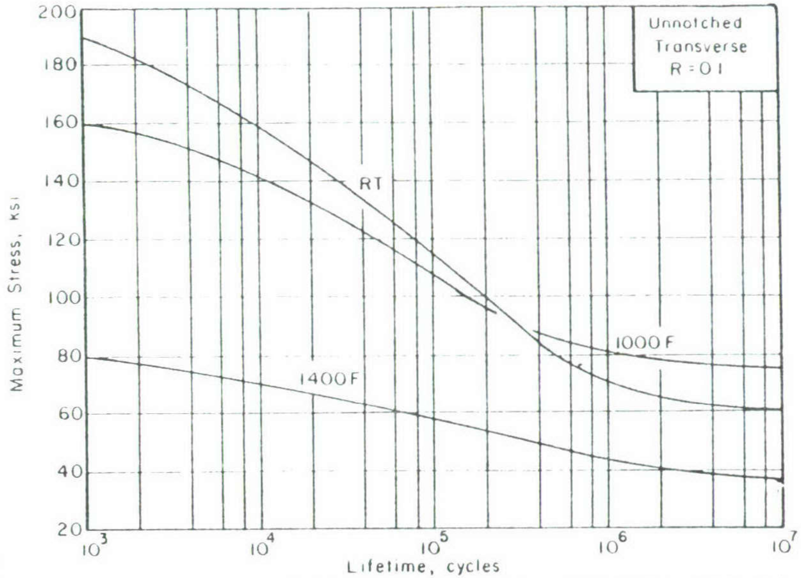


FIGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED AF2-1DA SHEET AT THREE TEMPERATURES

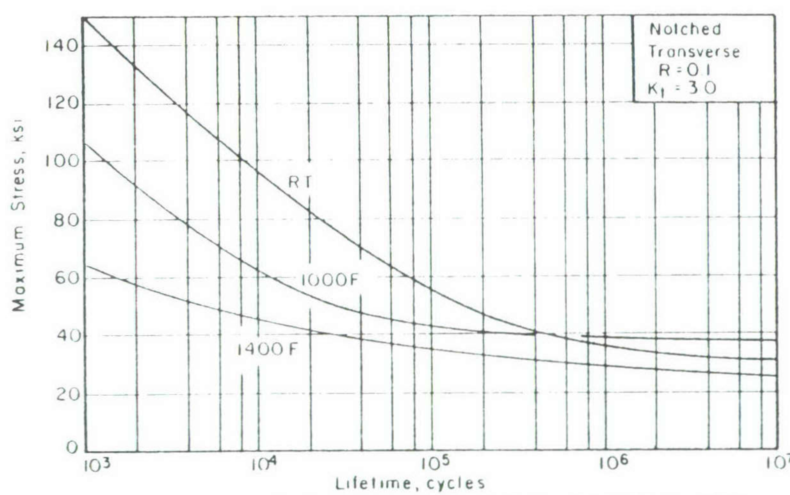


FIGURE 4 AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) AF2-1DA SHEET AT THREE TEMPERATURES

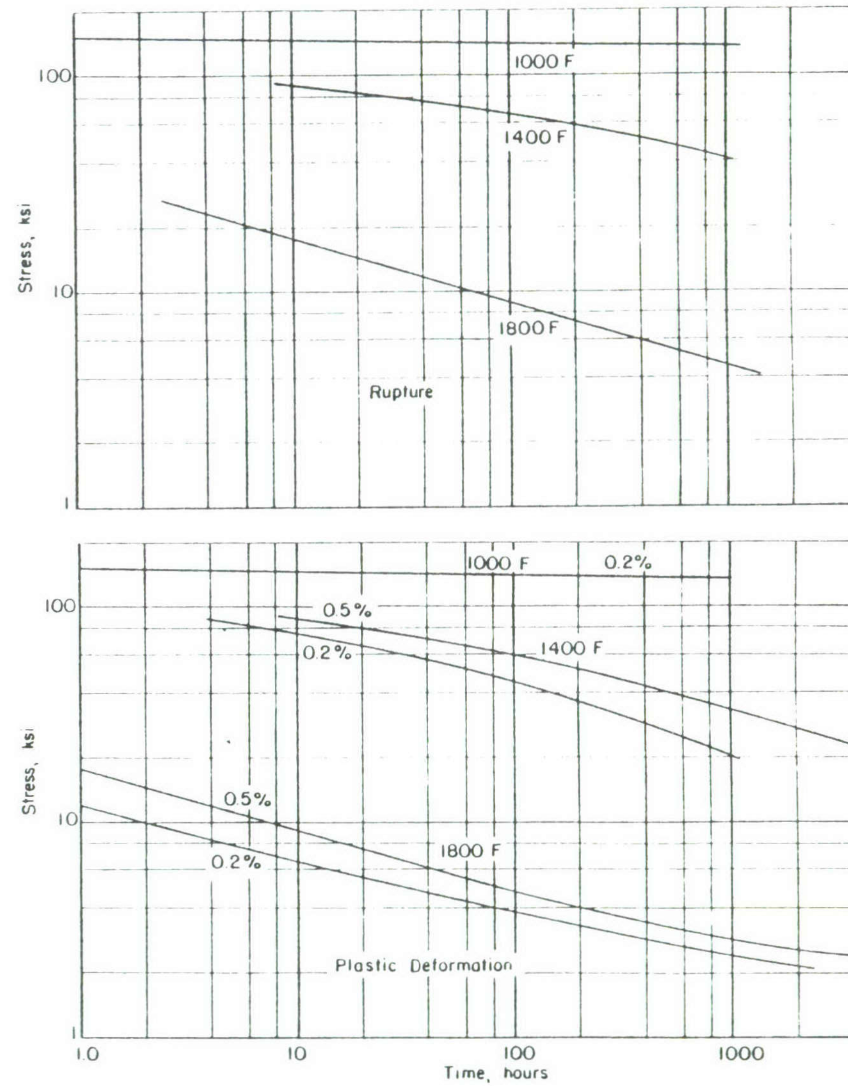


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR AF2-1DA SHEET AT THREE TEMPERATURES

Custom 455 Alloy

Custom 455 is a new martensitic age-hardenable stainless steel developed by The Carpenter Research Laboratories of Carpenter Technology Corporation. The alloy is relatively soft and easily formable in the annealed condition. A simple, single-step aging treatment develops good yield strengths with good ductility and toughness.

The new stainless steel can be machined in the annealed condition, and welded in the same manner as other stainless steels. It is easily formable because of its low work hardening rate. The dimensional change during hardening is only about 0.001 in/in which permits close-tolerance finish machining in the annealed state.

Custom 455 is designed to be used where simplicity of heat treatment, ease of fabrication, high strength and corrosion resistance are required in combination. It is available as hot rolled and cold finished strip, cold finished rounds, hot rolled bars, wire, and shapes, tubular products and billets. The nominal composition of Custom 455 is as follows.

C	Mn	Si	Cr	Ni	Ti	Cb	Cu	Fe
0.03	0.25	0.25	11.75	8.50	1.20	0.30	2.25	Balance

Custom 455 Data[a]

Condition: Aged
Thickness: 1-inch-diameter Bar

Properties	RT	Temperature, F 400	600	800
Tension				
TUS (longitudinal), ksi	248.4	215.9	201.2	180.6
TYS (longitudinal), ksi	247.4	214.4	197.2	174.1
e_t (longitudinal), percent in 2 in.	10.0	10.6	11.8	14.7
RA (longitudinal), percent	45.3	50.0	54.2	63.2
E_t (longitudinal), 10^6 psi	28.3	27.8	26.7	24.5
Compression				
CYS (longitudinal), ksi	255.4	218.3	202.0	177.7
E_c (longitudinal), 10^6 psi	29.7	27.7	26.5	23.9
Shear[b]				
SUS (longitudinal), ksi	152.0	U[d]	U	U
Impact[c]				
V-notch Charpy, ft lb	15.0	U	U	U
Fracture Toughness[e]				
K_{Ic}, ksi$\sqrt{in.}$	55.8	U	U	U
Axial Fatigue (Longitudinal)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	240	220	U	188
10^5 cycles, ksi	131	127	U	123
10^7 cycles, ksi	120	120	U	104
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	150	134	U	133
10^5 cycles, ksi	45	60	U	60
10^7 cycles, ksi	30	44	U	44
Creep (Longitudinal)				
0.2% plastic deformation, 100 hr	NA	207	163	44[g]
0.2% plastic deformation, 1000 hr	NA	203	155	30[g]
Stress Rupture (Longitudinal)				
Rupture, 100 hr	NA	216	193	99[g]
Rupture, 1000 hr	NA	215	188	77[g]
Stress Corrosion				
80% TYS, 1000 hr max	No cracks[h]			

Properties	RT	Temperature, F 400	 600	 800
<u>Coefficient of Thermal Expansion</u>				
6.08×10^{-6} in./in./F (72 to 400 F)				
6.57×10^{-6} in./in./F (72 to 800 F)				
<u>Density</u>				
0.280 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250 inch diameter.

(c) 10.0 at -90 F.

(d) U, unavailable; NA, not applicable.

(e) Slow-bend chevron-notched-type specimen.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Data for 850 F.

(h) Room-temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

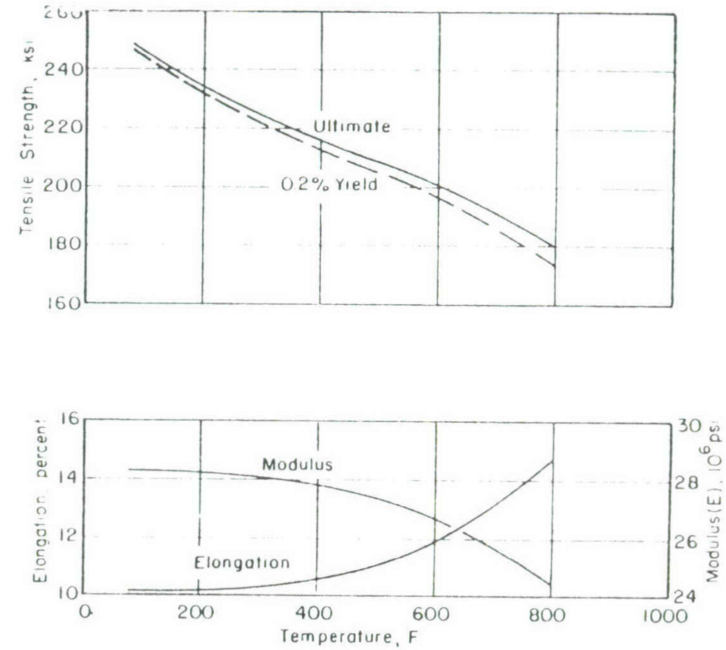


FIGURE 1 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CUSTOM 455 ROUND BAR

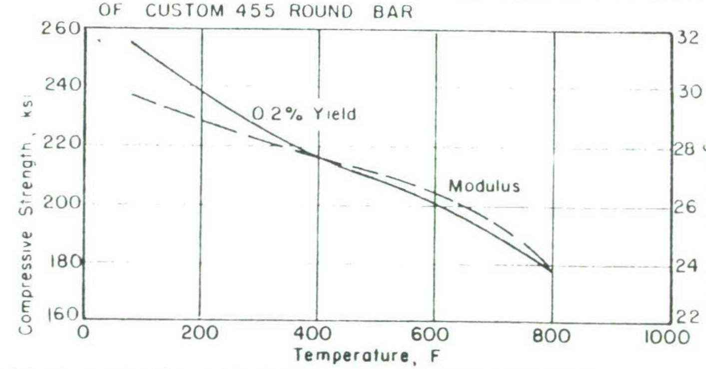


FIGURE 2 EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF CUSTOM 455 ROUND BAR

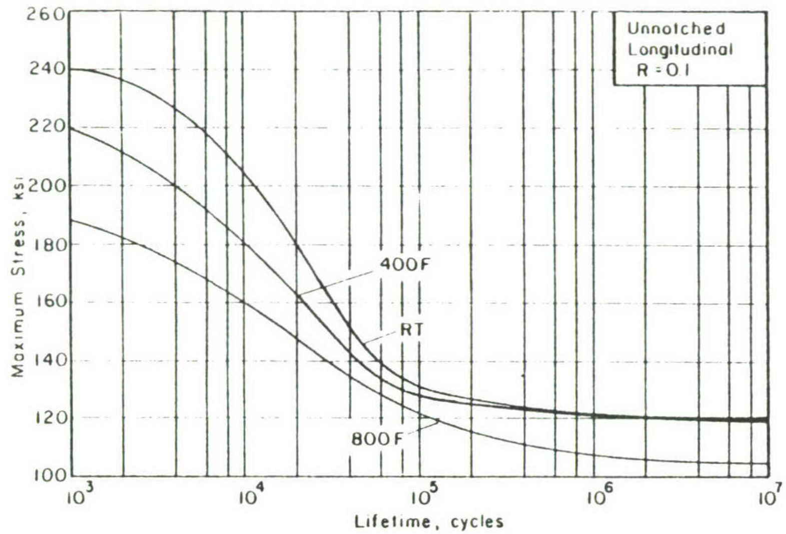


FIGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED CUSTOM 455 ROUND BAR AT THREE TEMPERATURES

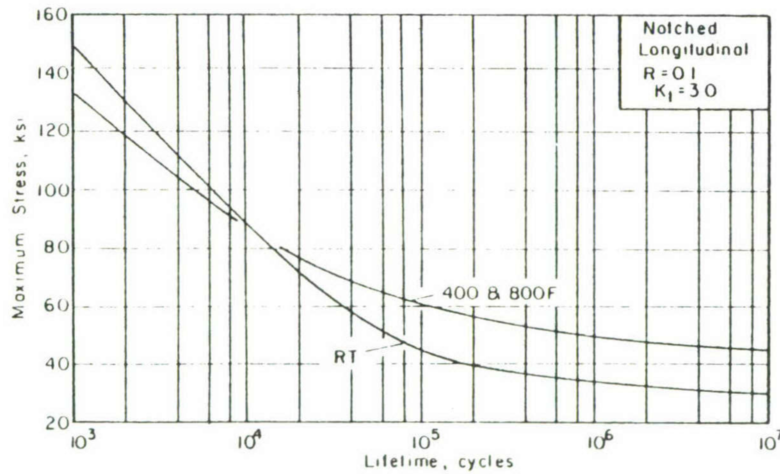


FIGURE 4 AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED ($K_t = 3.0$) CUSTOM 455 ROUND BAR AT THREE TEMPERATURES

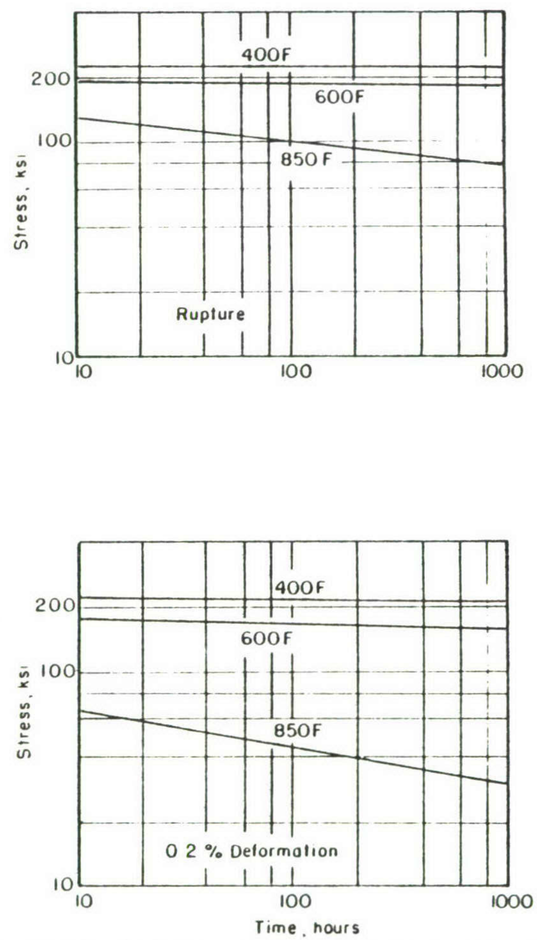


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR CUSTOM 455 ROUND BAR

HA-188 Alloy

Haynes Alloy 188 is a new cobalt-base alloy development of the Stellite Division of The Cabot Corporation. It is reported to have excellent high-temperature strength and oxidation resistance, and good post-aging ductility. It can be strengthened and hardened by cold work. The alloy can be welded by conventional techniques and exhibits good restraint-welding characteristics. Studies are now in progress to define the aging characteristics of this alloy.

The nominal composition of Alloy 188 is as follows.

Cr	W	C	Ni	Si	Mn	Fe	La	Co
22.0	14.0	0.08	22.0	0.20	0.75	1.5	0.08	Balance

HA-188 Data[a]

Condition: Annealed
Thickness: 0.078-inch sheet

Properties	Temperature, F RT	600	1000	1400
Tension				
TUS (longitudinal), ksi	146.0	128.5	119.5	70.1
TUS (transverse), ksi	145.5	127.5	118.0	70.7
TYS (longitudinal), ksi	78.5	55.2	51.3	46.9
TYS (transverse), ksi	68.7	49.0	45.7	44.2
e_t (longitudinal), percent in 2 in.	60.0	63.5	56.5	50.5
e_t (transverse), percent in 2 in.	59.8	63.5	56.5	48.7
E_t (longitudinal), 10^6 psi	35.1	36.4	30.5	26.3
E_t (transverse), 10^6 psi	34.6	33.1	32.5	24.2
Compression				
CYS (longitudinal), ksi	50.0	43.5	41.3	44.2
CYS (transverse), ksi	73.8	54.9	49.5	46.2
E_c (longitudinal), 10^6 psi	33.2	30.1	30.5	24.5
E_c (transverse), 10^6 psi	33.0	29.5	29.0	25.7
Shear[b]				
SUS (longitudinal), ksi	132.8	U[e]	U	U
SUS (transverse), ksi	137.1	U	U	U
Bend[c]				
Longitudinal, minimum radius	T/5	U	U	U
Transverse, minimum radius	T/5	U	U	U
Fracture Toughness, K_c				
ksi$\sqrt{in.}$	(d)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	145	U	120	70
10^5 cycles, ksi	116	U	91	50
10^7 cycles, ksi	80	U	66	45
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	138	U	94	65
10^5 cycles, ksi	67	U	60	36
10^7 cycles, ksi	40	U	40	30

HA-188 Data (continued)

Properties	RT	Temperature, F 800	1200	1600
Creep (transverse)				
0.2% plastic deformation, 100 hr	NA	116	44	9
0.2% plastic deformation, 1000 hr	NA	115	33	7
Stress Rupture, transverse				
Rupture, 100 hr	NA	116.5	65	16
Rupture, 1000 hr	NA	115.5	50	11
Stress Corrosion				
80% TYS, 1000-hour maximum	No cracks(g)			
Coefficient of Thermal Expansion				
6.8×10^{-6} in./in./F (78 to 600 F)				
9.2×10^{-6} in./in./F (78 to 1400 F)				
Density				
0.333 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Single-shear sheet-type specimens.

(c) Specimens tested at RT, +32, and -90 F. No cracks at either temperature.

(d) Specimens were full sheet thickness x 18 in. x 48 in. with EDM flaw in center. Average K_i was 175 ksi$\sqrt{\text{in.}}$ The net section yield stress at fracture was greater than the tensile yield strength of the material; therefore, the K values are considered not valid.

(e) U, unavailable; NA, not applicable.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

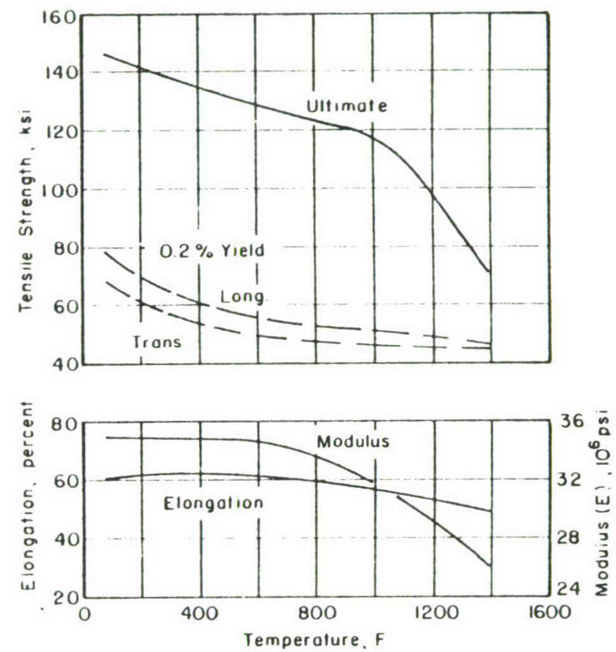


FIGURE 1 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HA-188 SHEET

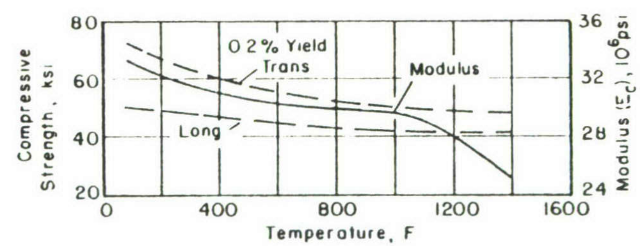


FIGURE 2 EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF HA-188 SHEET

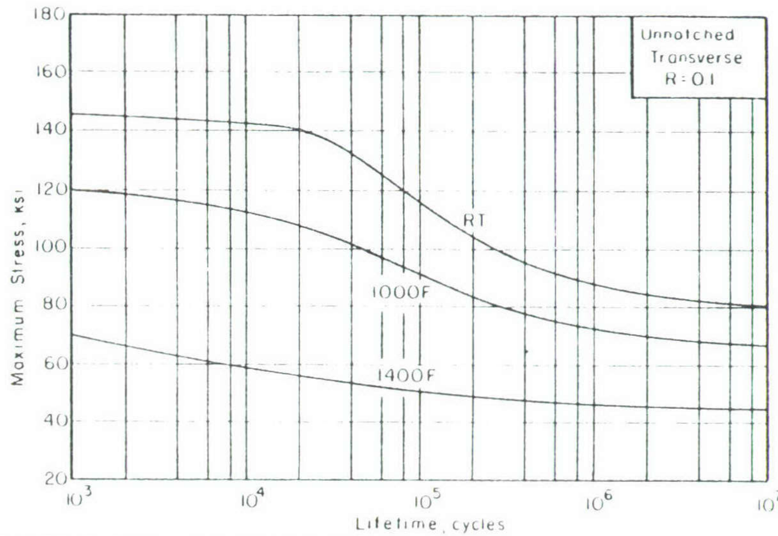


FIGURE 3 AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED HA 188 SHEET AT THREE TEMPERATURES

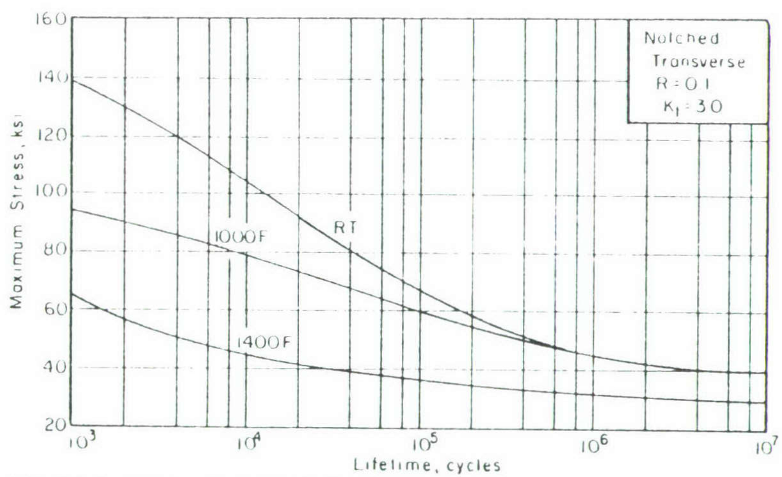


FIGURE 4 AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) HA-188 SHEET AT THREE TEMPERATURES

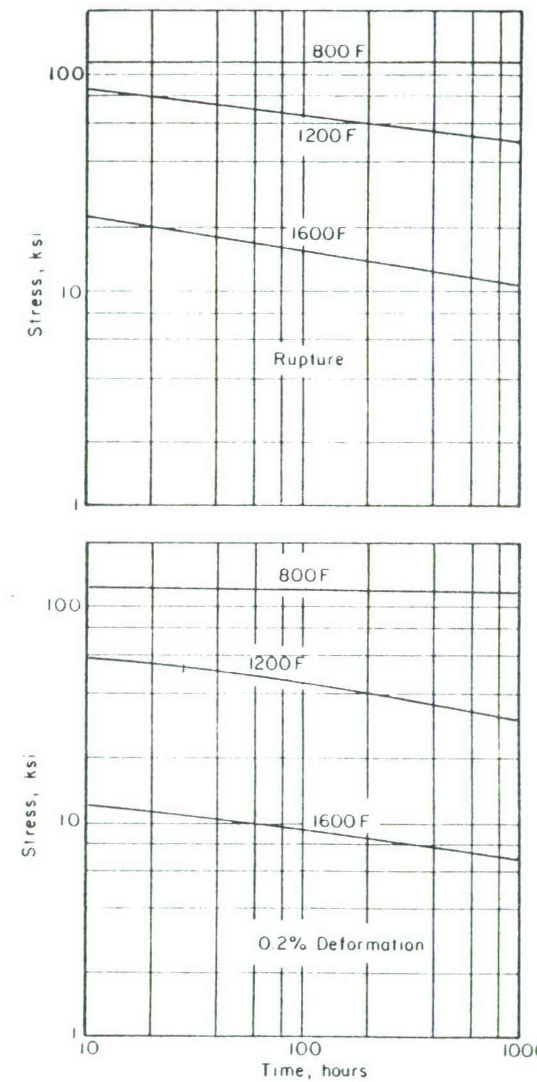


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR HA-188 SHEET

X5090-H38 Aluminum Alloy

Alloy X5090 is a development of the Aluminum Division, Olin Corporation. As a basic Aluminum-7% Magnesium alloy, it is designed to offer exceptional mechanical properties in the cold-worked and stabilized temper without susceptibility to stress corrosion cracking. A combination of controlled chemistry of minor elements and controlled thermal processing has resulted in light gage, full-hard sheet material with mechanical properties in excess of those of 2024-T3. The alloy, as reported by Olin, is characterized by low density, excellent fracture toughness, excellent fatigue strength, and excellent general corrosion resistance, as well as freedom from susceptibility to stress corrosion cracking.

Composition limits of this alloy are as follows:

Si	0.50 max
Fe	0.50 max
Cu	0.25 max
Mn	0.35 max
Mg	6.0 to 8.0
Cr	0.05 to 0.30
Zn	0.20 max
Ti	0.015 max
Be	0.001 to 0.02
B	0.001 to 0.050
Others	0.15 max

The H38 condition is 75 percent cold-rolled and stabilized.

X5090 Aluminum Data[a]

Condition: -H38
Thickness: 0.025-inch sheet

Properties	Temperature, F RT	200	325	400
Tension				
TUS (longitudinal), ksi	73.9	62.9	35.9	19.2
TUS (transverse), ksi	72.3	62.0	41.5	22.9
TYS (longitudinal), ksi	58.7	54.6	30.5	13.3
TYS (transverse), ksi	52.8	50.7	37.6	19.9
e_t (longitudinal), percent in 2 in.	6.8	13.0	47.0	79.3
e_t (transverse), percent in 2 in.	9.0	21.0	39.0	49.3
E_t (longitudinal), 10^6 psi	12.9	9.4	7.1	4.5
E_t (transverse), 10^6 psi	10.5	9.4	7.5	5.1
Compression				
CYS (longitudinal), ksi	57.5	58.0	41.6	19.1
CYS (transverse), ksi	63.5	66.1	47.1	28.9
E_c (longitudinal), 10^6 psi	10.5	10.6	8.1	6.8
E_c (transverse), 10^6 psi	10.7	11.2	8.2	6.7
Shear[b]				
SUS (longitudinal), ksi	43.0	U[c]	U	U
SUS (transverse), ksi	41.9	U	U	U
Bend				
Longitudinal, minimum radius	4t	U	U	U
Transverse, minimum radius	3.5t	U	U	U
Fracture Toughness, K_c[d] ksi$\sqrt{in.}$	49	U	U	U
Axial Fatigue (transverse)				
Unnotched, R = 0.1[e]				
10^5 cycles, ksi	73	60	50	U
10^6 cycles, ksi	43	37	30	U
10^7 cycles, ksi	30	26	13	U
Notched, K_t = 3.0, R = 0.1				
10^5 cycles, ksi	50	48	38	U
10^6 cycles, ksi	22	18	13	U
10^7 cycles, ksi	14	12	5	U
Creep (transverse)				
0.5% plastic deformation, 100 hr	NA	25	6	3
0.5% plastic deformation, 1000 hr	NA	8	3.5	2

Properties	RT	Temperature, F 200	325	400
<u>Stress Rupture (transverse)</u>				
Rupture, 100 hr	NA	41	15	7
Rupture, 1000 hr	NA	35	10	4.5
<u>Stress Corrosion</u>				
80% TYS, 1000-hour maximum	No cracks(f)			

<u>Coefficient of Thermal Expansion</u>

12.8×10^{-6} in./in./F (68 to 212 F)

<u>Density</u>

0.095 lb/in.^{3}

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract, unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Single shear sheet type test.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 in. x 48 in. with EDM flaw in center. The net section yield stress at fracture was less than the tensile yield strength of the material; therefore, the K values are considered valid.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; i.e., $R = S_{min}/S_{max}$. "K_t" represents the Neuber Peterson theoretical stress concentration factor.

(f) Room-temperature three point bend test. Alternate immersion in 3½ percent NaCl.

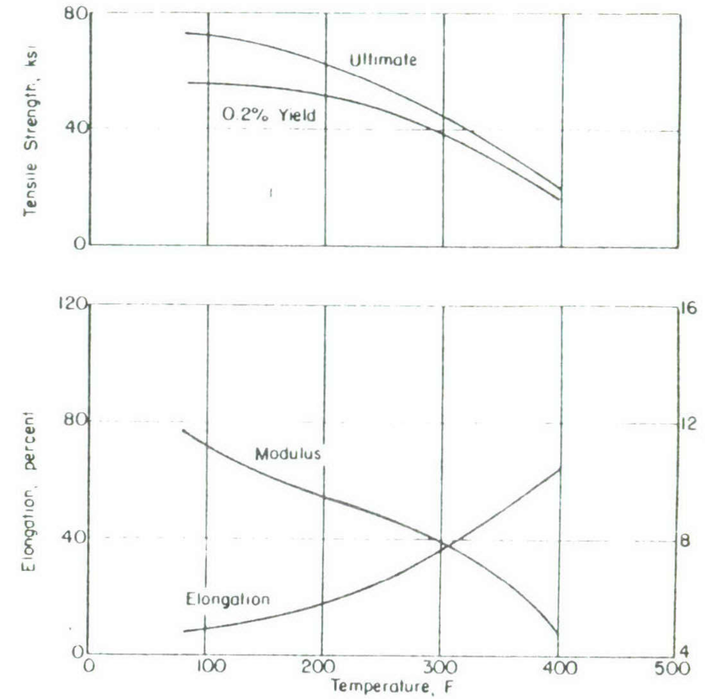


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF X5090 ALUMINUM ALLOY

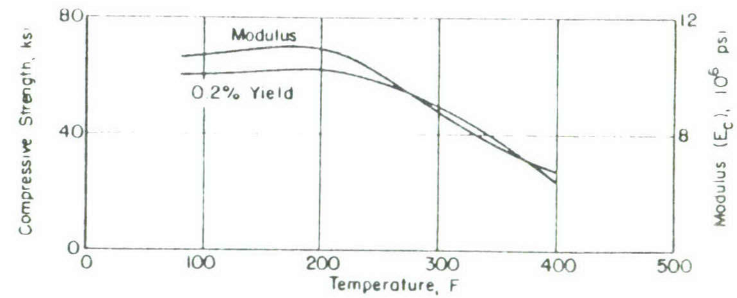


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF X5090 ALUMINUM ALLOY

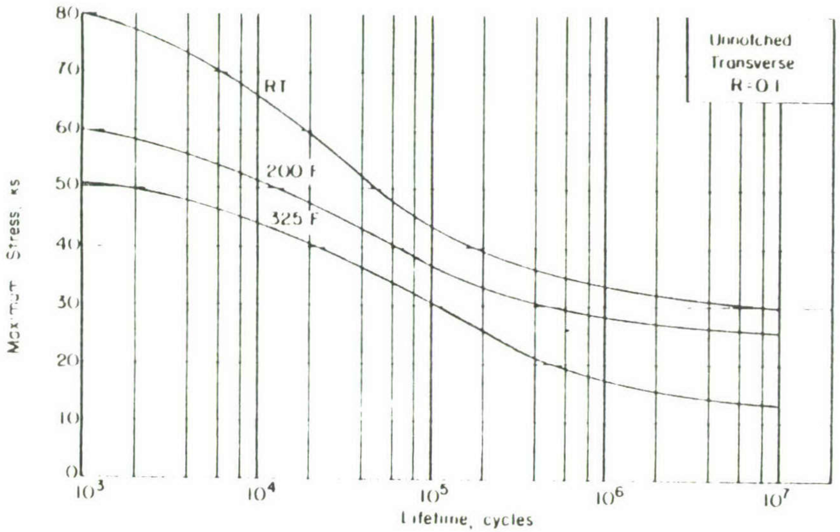


FIGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED X5090 ALUMINUM SHEET AT THREE TEMPERATURES

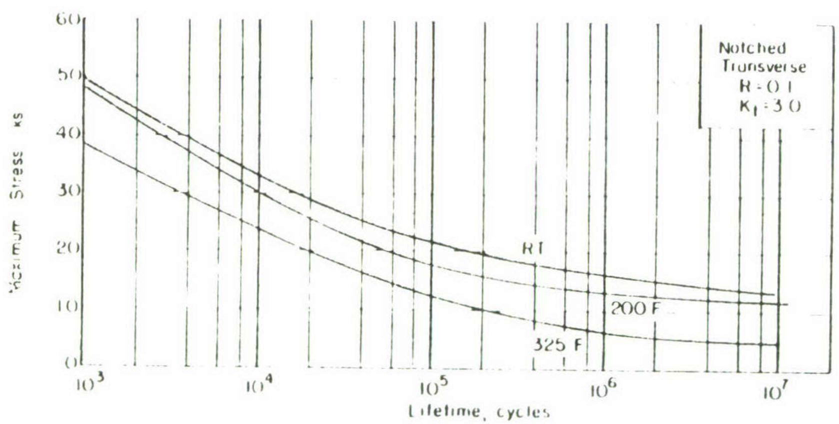


FIGURE 4 AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) X5090 ALUMINUM SHEET AT THREE TEMPERATURES

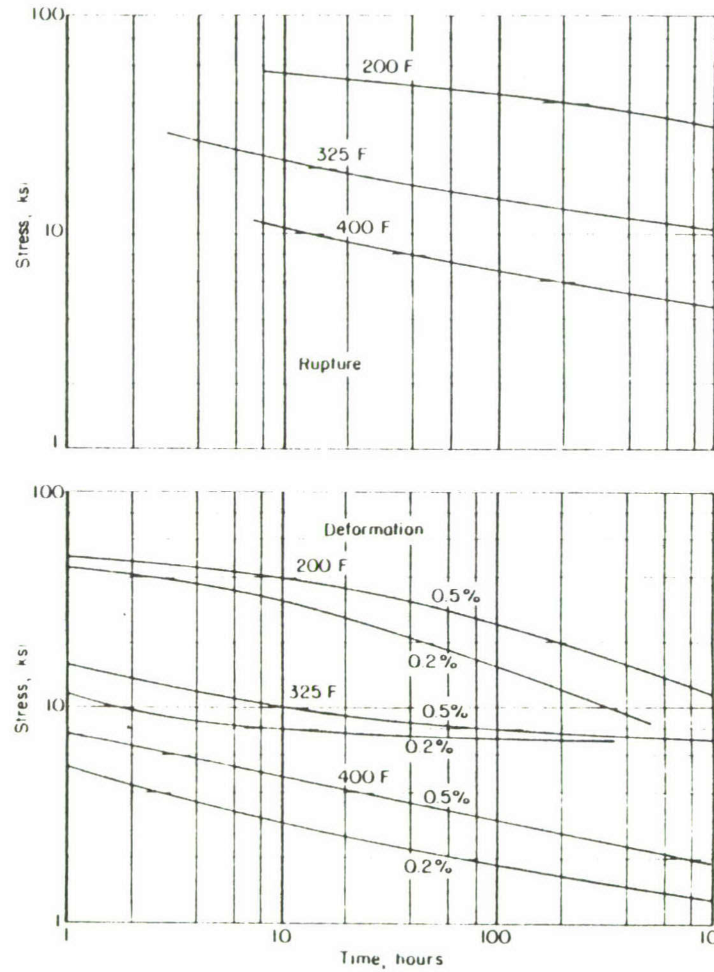


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR X-5090 ALUMINUM SHEET AT THREE TEMPERATURES

Udimet 700 Alloy

Udimet 700 is one of the older heat-resistant nickel-base alloys that has seen limited use in engines as forging and bar products. The Air Force has funded an intensive effort (Contract AF 33(615)-3883) at Union Carbide Corporation to develop a sheet manufacturing process for this alloy. The material for this evaluation was supplied GFM from this effort. History and processing for the Udimet 700 sheet is contained in Reference 1. The specimens were heat-treated as follows:

2150F for 2 hours with rapid air cool,

1950F for 4 hours with air cool,

1550 F for 24 hours with air cool,

1400 F for 16 hours with air cool.

According to Reference 1, this heat treatment is designed to give the best stress-rupture properties while maintaining good mechanical properties.

(1) Kelley, E. W., "Manufacturing Process for Improved High-Strength Superalloy Sheet", AFML-TR-69-114 (June 1969).

Udimet 700 Data(a)

Condition: STA
Thickness: 0.032-inch sheet

Properties	RT	1000	1400	180
	Temperature, F			
Tension				
TUS (longitudinal), ksi	224.7	213.0	127.3	26.
TUS (transverse), ksi	213.7	199.7	127.7	26.
TYS (longitudinal), ksi	150.7	139.7	121.3	22.
TYS (transverse), ksi	150.0	138.3	124.7	22.
e_t (longitudinal), percent in 2 in.	21.7	15.7	34.7	44.
e_t (transverse), percent in 2 in.	21.0	16.7	26.7	40.
E_t (longitudinal), 10^6 psi	32.9	29.1	23.2	13.
E_t (transverse), 10^6 psi	34.1	31.7	25.4	13.
Compression				
CYS (longitudinal), ksi	161.3	146.7	125.0	21.
CYS (transverse), ksi	161.0	147.7	125.0	21.
E_c (longitudinal), 10^3 ksi	33.5	31.0	24.3	12.
E_c (transverse), 10^3 ksi	36.2	33.0	24.6	11.
Shear(b)				
SUS (longitudinal), ksi	143.2	U(c)	U	U
SUS (transverse), ksi	148.0	U	U	U
Bend				
Longitudinal, minimum radius	1.5-2t	U	U	U
Transverse, minimum radius	1.5-2t	U	U	U
Fracture Toughness, K_c(d) ksi$\sqrt{\text{in.}}$	2.0	U	U	U
Axial Fatigue (transverse)				
Unnotched, R = 0.1(e)				
10^3 cycles, ksi	200	190	162	U
10^6 cycles, ksi	152	140	136	U
10^7 cycles, ksi	80	126	96	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	158	140	110	U
10^6 cycles, ksi	75	68	68	U
10^7 cycles, ksi	42	52	60	U
Creep (transverse)				
0.2% plastic deformation, 100 hr	NA(c)	150	35	0.
0.2% plastic deformation, 1000 hr	NA	100	12	0.

Udimet 700 Data (Continued)

Properties	RT	Temperature, F 1000	1400	1800
Stress Rupture (transverse)				
Rupture, 100 hr	NA	180	60	3.5
Rupture, 1000 hr	NA	150	38	1.5
Stress Corrosion				
80% TYS, 1000-hour maximum	No cracks(f)			
Coefficient of Thermal Expansion				
8.0×10^{-6} in./in./F (RT to 1200 F)				
Density				
0.285 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract, unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Single-shear sheet-type test.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 in. x 48 in. with EDM flaw in center. The net section yield stress at fracture was less than the tensile yield strength of the material; therefore, the F values are considered valid.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; i.e., $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3½ percent NaCl.

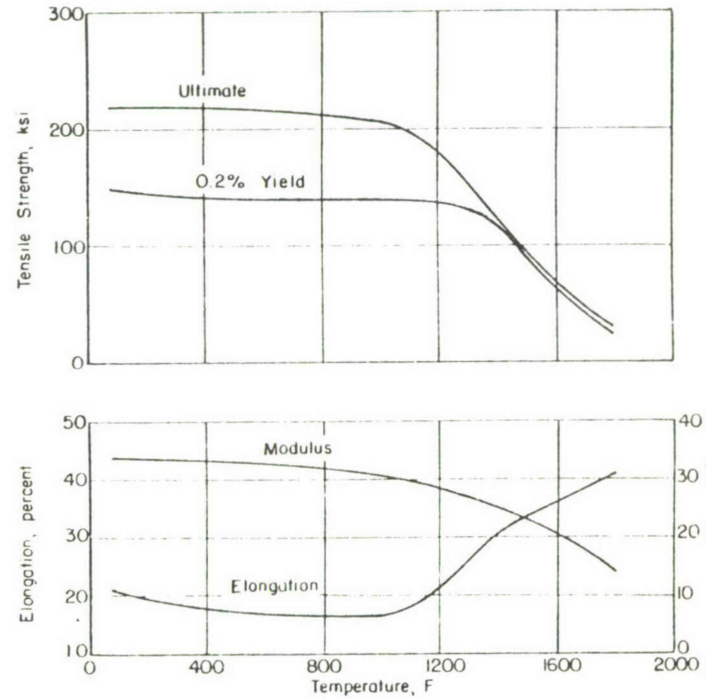


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF U-700 SHEET

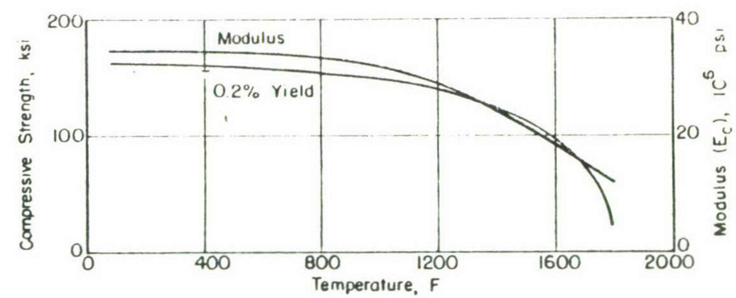
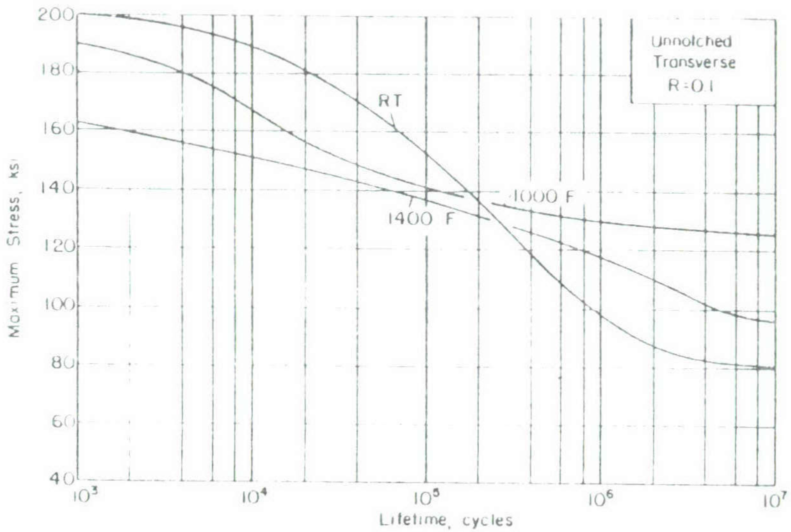


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF U-700 SHEET



IGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR U-700 SHEET

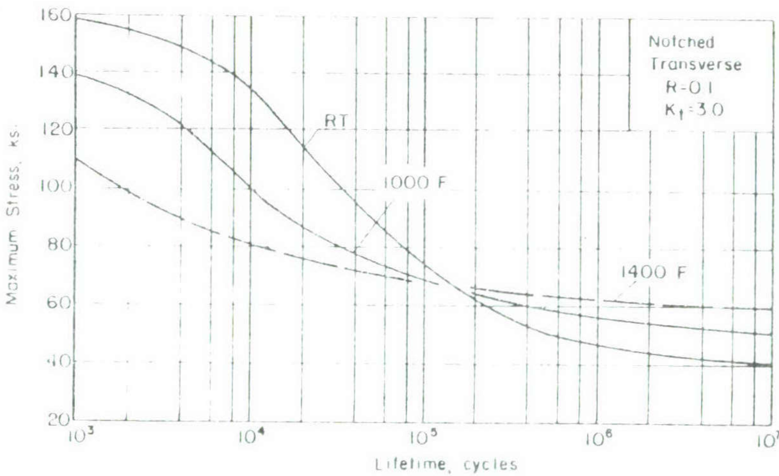


FIGURE 4 AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) U-700 SHEET

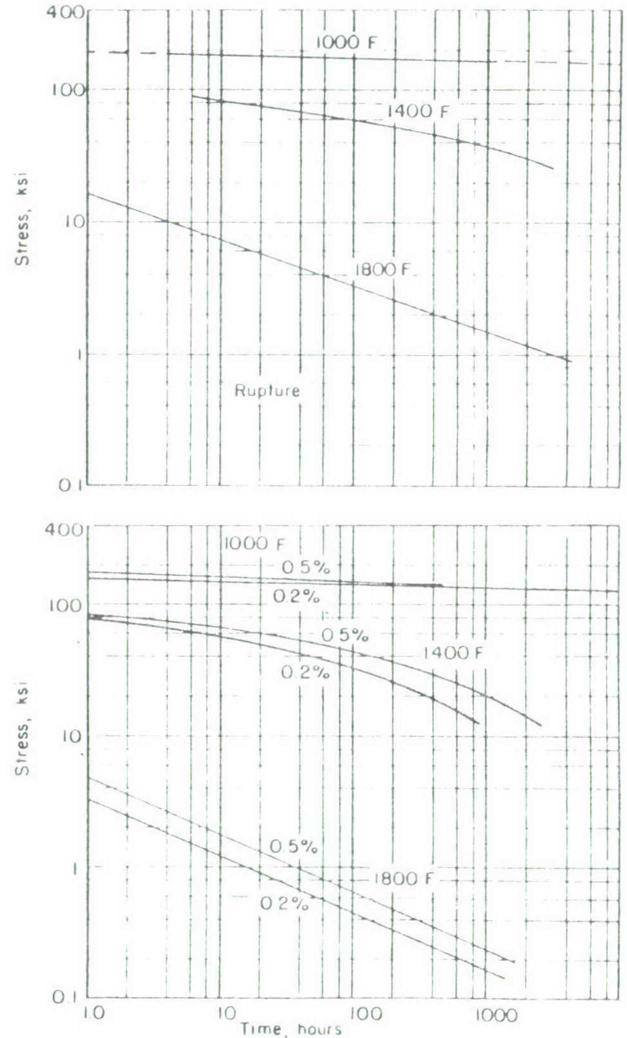


FIGURE 5 STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR UDIMET-700 AT THREE TEMPERATURES

Ti - 6 Al - 2 Sn - 4 Zr - 2 Mo Alloy

This is one of the so-called "super" alpha alloys having an alpha-stabilized Ti-Al matrix solid solution strengthened by the additions of tin and zirconium. The beta-stabilizing addition, molybdenum, increases room and elevated temperature tensile strength and stability. It was developed originally for jet engine usage, principally as forgings, however, it has also been produced as flat-rolled products. The alloy possesses good strength and stability up to 1000 F. Its formability and weldability compare favorably with other titanium alloys.

The composition of the material used in this evaluation was as follows.

C	Fe	N	Al	Mo	H	Zr	Sn	O
0.026	0.08	0.008	5.8	2.0	0.007	4.2	2.1	0.10

Ti
Balance

Ti - 6 Al - 2 Sn - 4 Zr - 2 Mo Data[a]

Condition: Triplex-annealed
Thickness: 0.080-inch sheet

Properties	Temperature, F			
	RT	400	700	1000
Tension				
TUS (longitudinal), ksi	146.3	129.0	120.0	102.6
TUS (transverse), ksi	147.6	129.0	120.0	103.3
TYS (longitudinal), ksi	144.3	109.6	94.1	83.4
TYS (transverse), ksi	145.6	111.6	97.0	86.0
e_t (longitudinal), percent in 2 in.	3.0	10.8	11.5	17.2
e_t (transverse), percent in 2 in.	2.7	10.7	10.8	16.5
E_t (longitudinal), 10^6 psi	17.0	15.9	14.3	12.2
E_t (transverse), 10^6 psi	17.9	16.7	14.9	13.5
Compression				
CYS (longitudinal), ksi	156.3	116.0	101.0	91.7
CYS (transverse), ksi	168.6	125.0	108.6	101.0
E_c (longitudinal), 10^6 psi	18.6	17.5	15.4	14.1
E_c (transverse), 10^6 psi	19.9	18.3	16.5	15.2
Shear[b]				
SUS (longitudinal), ksi	100.0	U[c]	U	U
SUS (transverse), ksi	101.0	U	U	U
Fracture Toughness, K_c				
ksi $\sqrt{\text{in.}}$	135[d]	U	U	U
Axial Fatigue (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	102	102	101	U
10^5 cycles, ksi	40	50	40	U
10^7 cycles, ksi	25	32	32	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	69	75	75	U
10^5 cycles, ksi	22	26	22	U
10^7 cycles, ksi	10	10	10	U
Creep (transverse)				
0.2% plastic deformation, 100 hr	NA[c]	106.0	99.0	20.0
0.2% plastic deformation, 1000 hr	NA	105.0	93.0	9.2

Ti - 6 Al - 2 Sn - 4 Zr - 2 Mo Data (continued)

Properties	Temperature, F			
	RT	400	700	1000
Stress Rupture (transverse)				
Rupture, 100 hr	NA	126.0	118.0	62.0
Rupture, 1000 hr	NA	125.0	117.0	37.0
Stress Corrosion				
80% TYS, 1000-hr maximum	No cracks(f)			
Coefficient of Thermal Expansion				
5.4×10^{-6} in/in/F (RT to 1000 F)				
Density				
0.164 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Single shear sheet type specimens.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 inches x 36 inches with EDM flow in center. The net section yield stress at fracture was less than the tensile yield strength of the material. The K value is considered valid.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle, that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

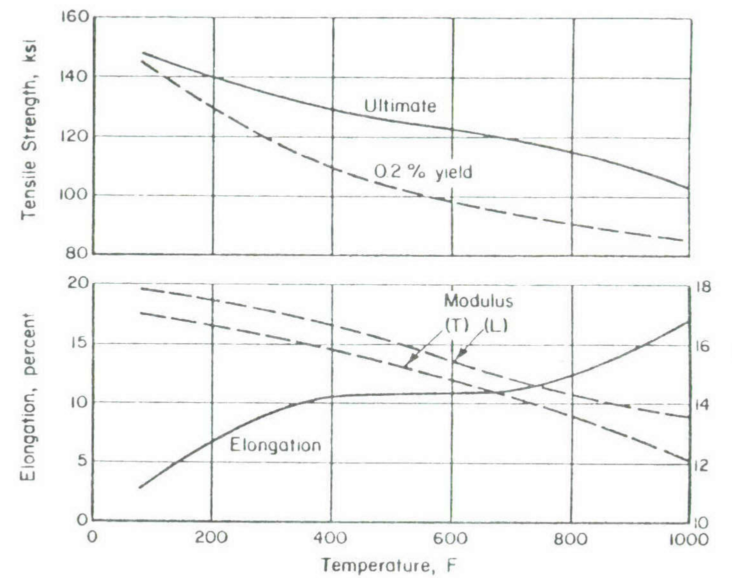


FIGURE 1 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo SHEET

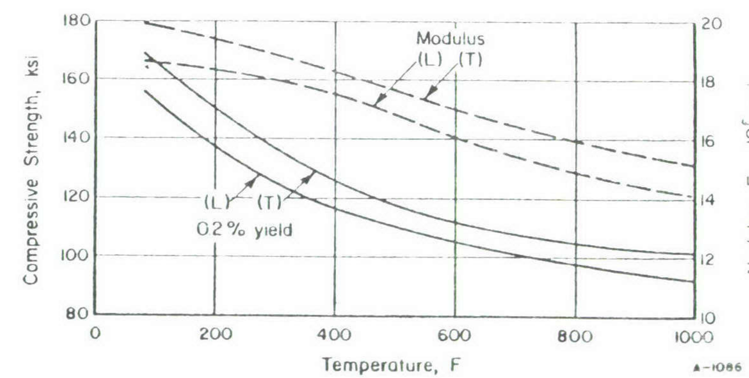


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo SHEET

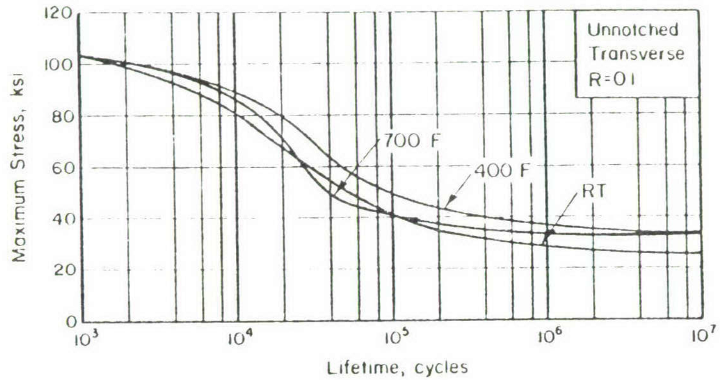


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR Ti-6Al-2Sn-4Zr-2Mo SHEET

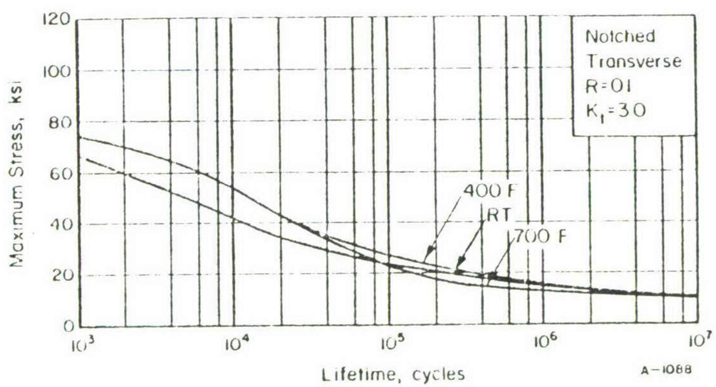


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) Ti-6Al-2Sn-4Zr-2Mo SHEET

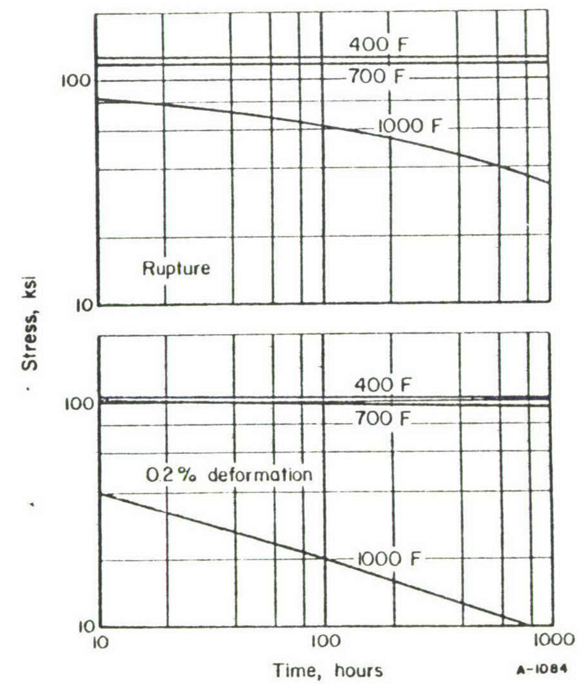


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Sn-4Zr-2Mo SHEET

PH 14-8 Mo Alloy

PH 14-8 Mo is a recent addition to the Armco Steel Company's family of precipitation hardenable stainless steels. It is a semiaustenitic alloy developed to provide a sheet and strip product with higher resistance to crack propagation than the older 17-7PH and PH15-7 Mo alloys. It is heat treatable to high strengths and exhibits good elevated temperature properties. Since it is austenitic in the annealed condition, it is readily formable by methods currently used for austenitic or other semiaustenitic steels. The alloy does work harden rapidly and may require intermediate anneals for deep drawn or other severly formed parts.

The alloy is commercially available in the form of sheet and strip.

The composition of the material used for this evaluation was as follows.

C	Mn	P	S	Si	Cr	Ni	Mo	Al
0.038	0.10	0.003	0.004	0.10	14.95	8.31	2.15	1.17

Fe
Balance

PH 14-8 Mo Data[a]

Condition: SRH 1050
Thickness: 0.070-inch sheet

Properties	RT	Temperature, F 400	700	900
Tension				
TUS (longitudinal), ksi	203.3	182.3	164.3	131.0
TUS (transverse), ksi	207.3	185.6	167.6	134.0
TYS (longitudinal), ksi	199.3	173.6	152.0	119.0
TYS (transverse), ksi	201.8	177.0	156.3	123.7
e_t (longitudinal), percent in 2 in.	7.5	6.0	9.6	18.2
e_t (transverse), percent in 2 in.	7.2	5.4	8.3	15.6
E_t (longitudinal), 10^6 psi	27.2	26.0	25.5	23.1
E_t (transverse), 10^6 psi	28.6	28.4	26.1	23.5
Compression				
CYS (longitudinal), ksi	218.3	197.6	176.6	137.6
CYS (transverse), ksi	219.0	203.0	180.6	146.6
E_c (longitudinal), 10^6 psi	27.6	25.5	25.2	24.4
E_c (transverse), 10^6 psi	30.5	27.1	26.3	25.7
Shear[b]				
SUS (longitudinal), ksi	130.2	U[c]	U	U
SUS (transverse), ksi	129.0	U	U	U
Bend				
minimum radius	IT	U	U	U
Fracture Toughness, K_c				
ksi $\sqrt{in.}$	270[d]	U	U	U
Axial Fatigue (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	190	185	170	U
10^5 cycles, ksi	102	92	86	U
10^7 cycles, ksi	90	80	76	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	119	117	110	U
10^5 cycles, ksi	41	38	44	U
10^7 cycles, ksi	30	30	40	U

PH 14-8 Mo Data (continued)

Properties	Temperature, F RT	400	700	900
Creep (transverse)				
0.2% plastic deformation, 100 hr	NA(c)			
0.2% plastic deformation, 1000 hr	NA			
Stress Rupture (transverse)				
Rupture, 100 hr	NA			
Rupture, 1000 hr	NA			
Stress Corrosion(f)				
80% TYS, 1000-hr maximum	No cracks			
Coefficient of Thermal Expansion				
10^{-6} in/in/F = (70-200 F) 5.3				
(70-600 F) 6.2				
(70-1000 F) 6.4				
Density				
0.278 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress rupture values are from curves generated using a greater number of tests.

(b) Single shear sheet type specimen.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 inches x 36 inches with EDM flow in center. The net section yield stress at fracture was less than the tensile yield strength of the material. The K value is considered valid.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

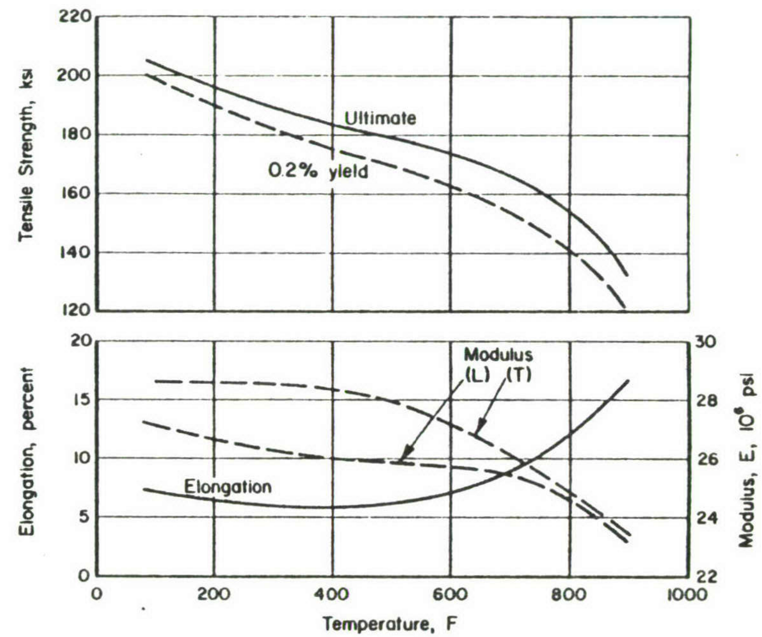


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF PH 14-8 Mo SHEET

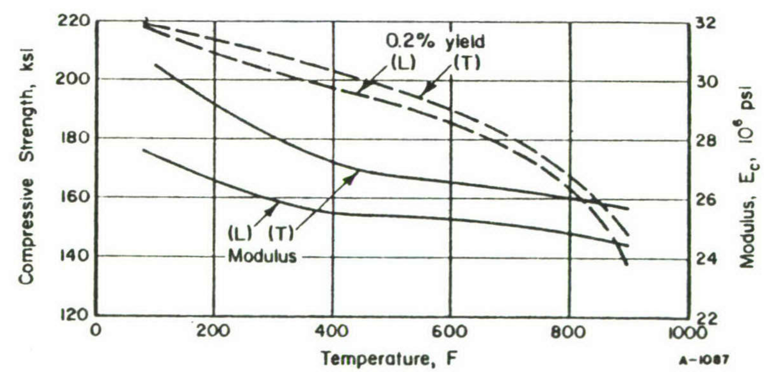


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF PH 14-8 Mo SHEET

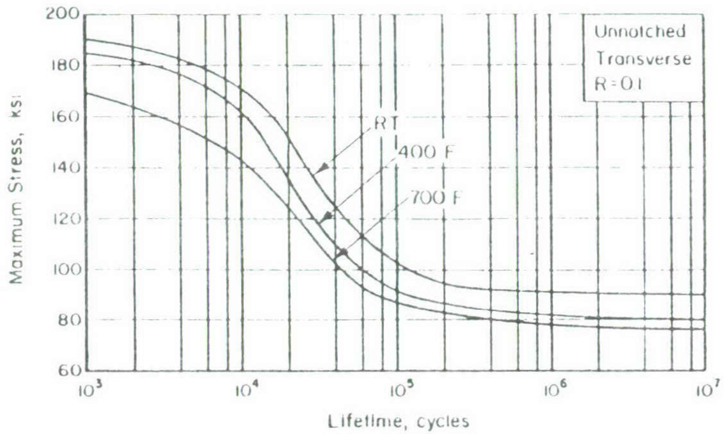


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR PH 14-8Mo SHEET

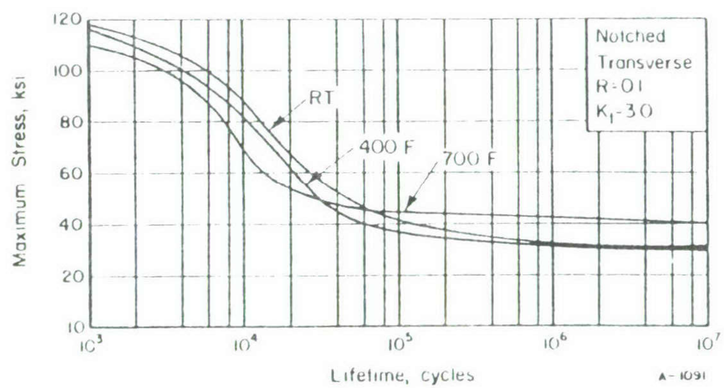


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) PH 14-8Mo SHEET

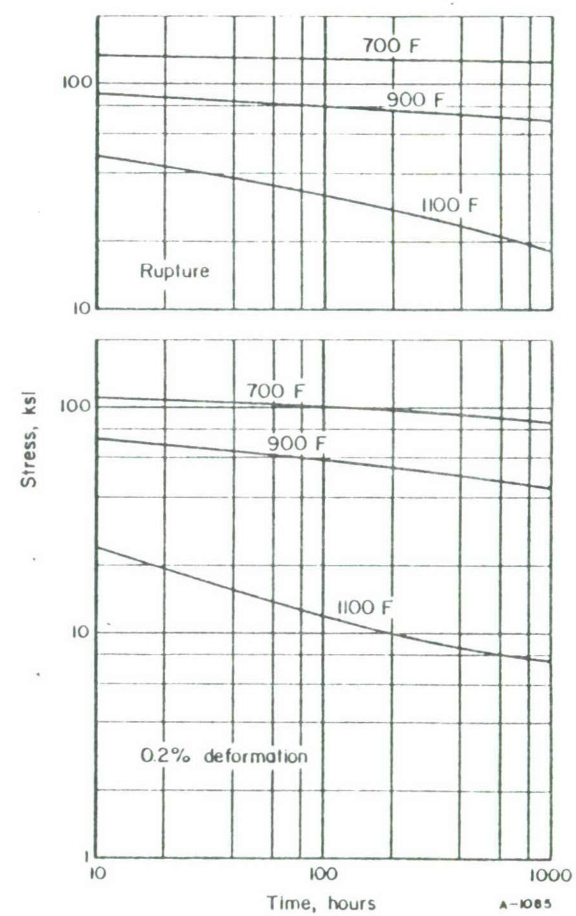


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR PH 14-8Mo SHEET

17-4 PH (H900) Bar (ESR)

Material Description

This alloy is one of the family of precipitation hardening stainless steels which have found wide usage in aerospace, industrial, and commercial applications. The particular material used in this evaluation was produced by the Electroslag Remelting (ESR) process. In this process an electrode (in this case, air melted 17-4 PH) is melted in a resistance heated molten bath of flux contained in an open-bottomed water-cooled metal mold. The melted metal forms a pool beneath the flux bath and progressively solidifies forming an ingot which is continuously extracted from the mold.

The metal is refined and desulfurized by flux action and the microstructure is improved by controlled solidification.

The material used in this evaluation was a 3.3-inch-diameter bar from Heat 02298. Chemistry was as follows:

Chemical Composition	Percent
Carbon	0.04
Manganese	0.70
Silicon	0.41
Phosphorus	0.15
Sulfur	0.08
Chromium	15.9
Nickel	4.45
Copper	3.45
Columbium	0.23
Iron	Balance

Processing and Heat Treating

Specimens were machined in the as-received Condition A followed by heat treatment at 900 F for 1 hour to Condition H 900.

17-4 PH ESR Data[a]

Condition: H900
Product: 3.3-inch diameter bar

Properties	Temperature, F RT	400	700	900
Tension				
TUS (longitudinal), ksi	197.2	177.5	160.4	139.4
TYS (longitudinal), ksi	185.6	159.3	145.0	108.2
e (longitudinal), percent in 2 in.	17.1	10.9	9.9	9.7
RA (longitudinal), percent	48.3	37.6	34.9	34.4
E (longitudinal), 10^6 psi	28.7	26.5	24.0	22.3
Compression				
CYS (longitudinal), ksi	173.1	147.9	139.5	117.6
E_c (longitudinal)	30.2	26.9	24.7	23.9
Shear[b]				
SUS (longitudinal), ksi	117.3	U[c]	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	22.2	U	U	U
(transverse)	21.7	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi $\sqrt{in.}$	48.2[e]	U	U	U
Axial Fatigue (longitudinal)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	170	139	118	U
10^5 cycles, ksi	121	109	99	U
10^7 cycles, ksi	103	90	74	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	136	90	76	U
10^5 cycles, ksi	39	53	48	U
10^7 cycles, ksi	30	50	42	U

17-4 PH ESR Data (continued)

Properties	RT	Temperature, F 700	900	1100
Creep (longitudinal)				
0.2% plastic deformation, 100 hr, ksi	NA	140	39	12
0.2% plastic deformation, 1000 hr, ksi	NA	130	18	4
Stress-Rupture (longitudinal)				
Rupture, 100 hr, ksi	NA	(h)	85	30
Rupture, 1000 hr, ksi	NA	(h)	50	16
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
6.5×10^{-6} in./in./F (68 to 900 F)				
Density				
0.283 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 5 tests.

(e) Three longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

(h) Not determinable from test results.

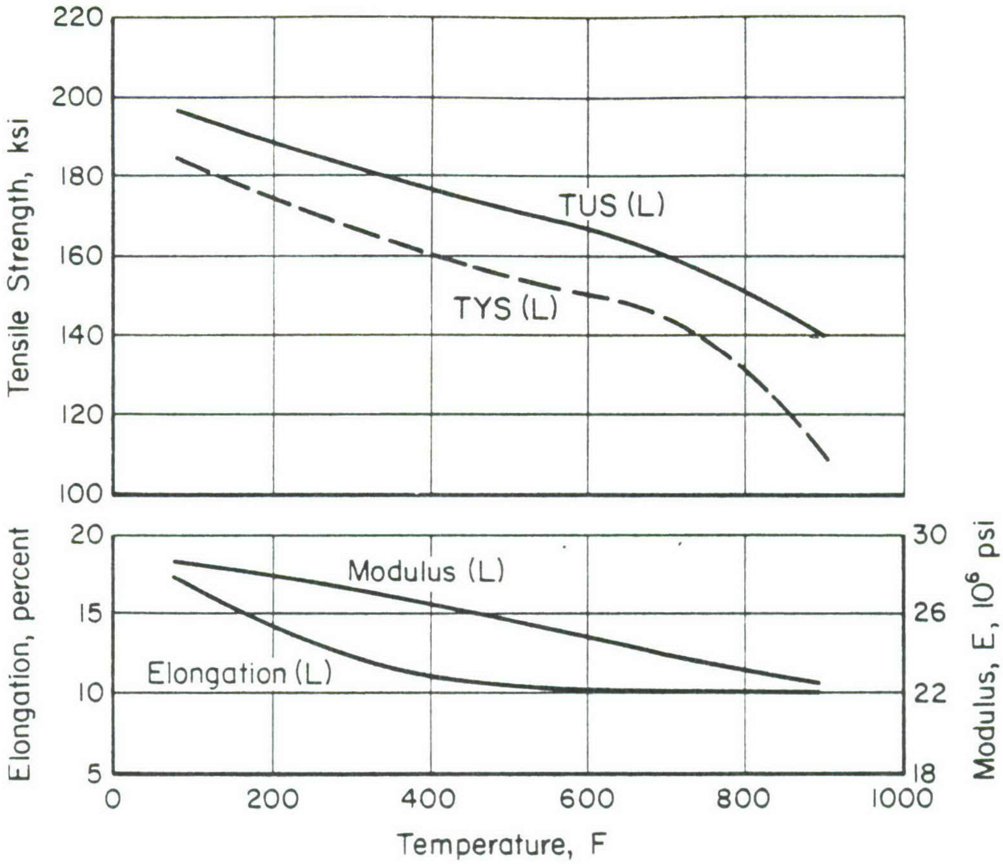


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 17-4 PH (H900) BAR (ESR)

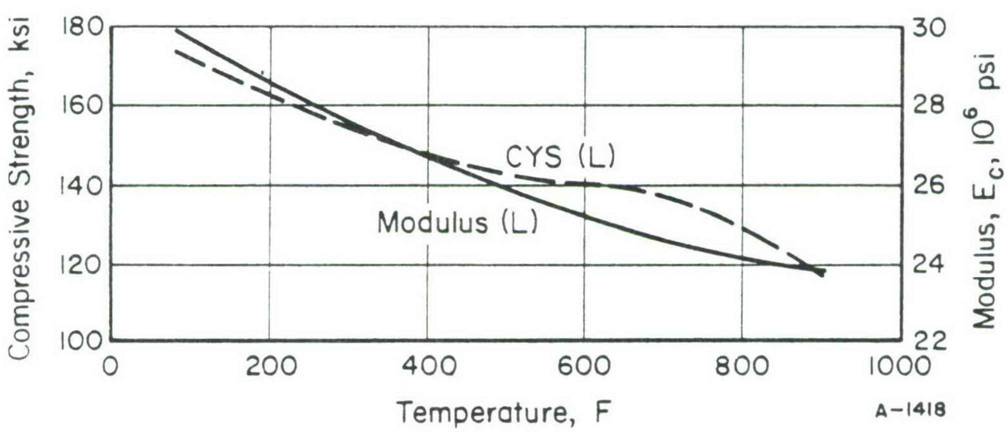


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 17-4 PH (H900) BAR (ESR)

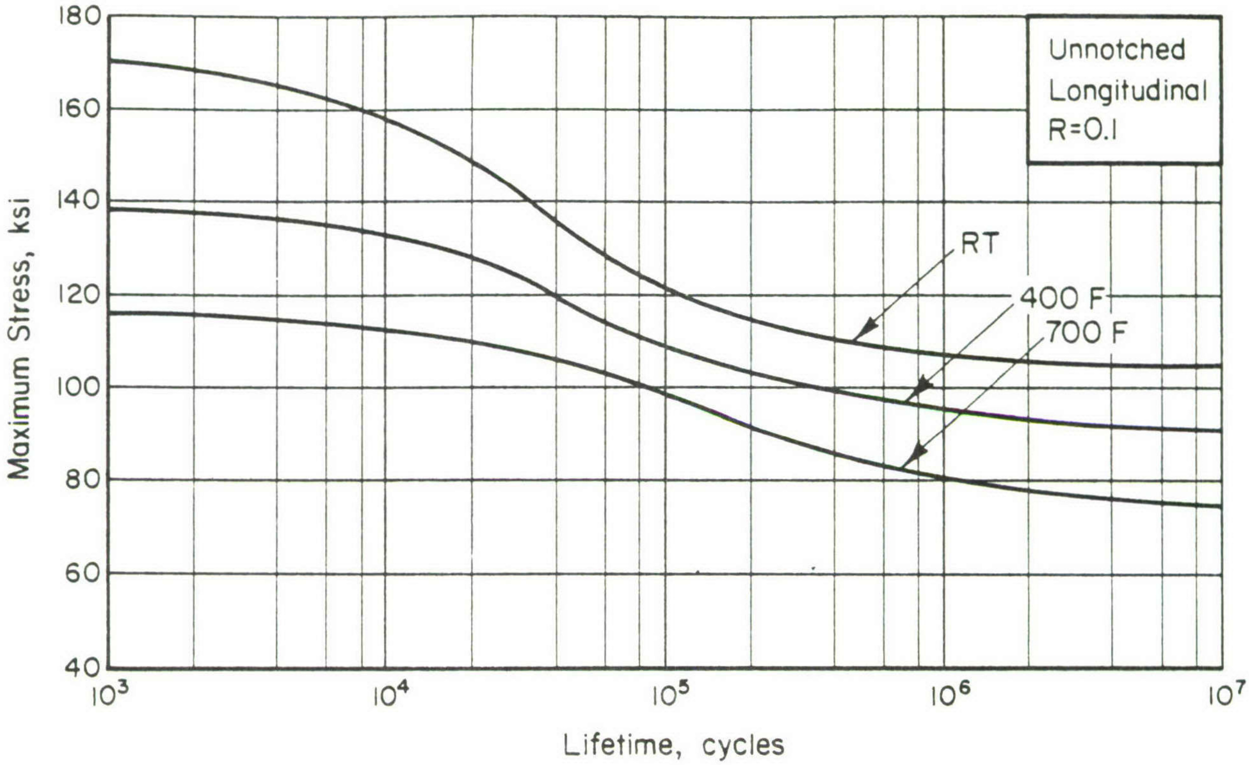


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 17-4 PH (H900) BAR (ESR)

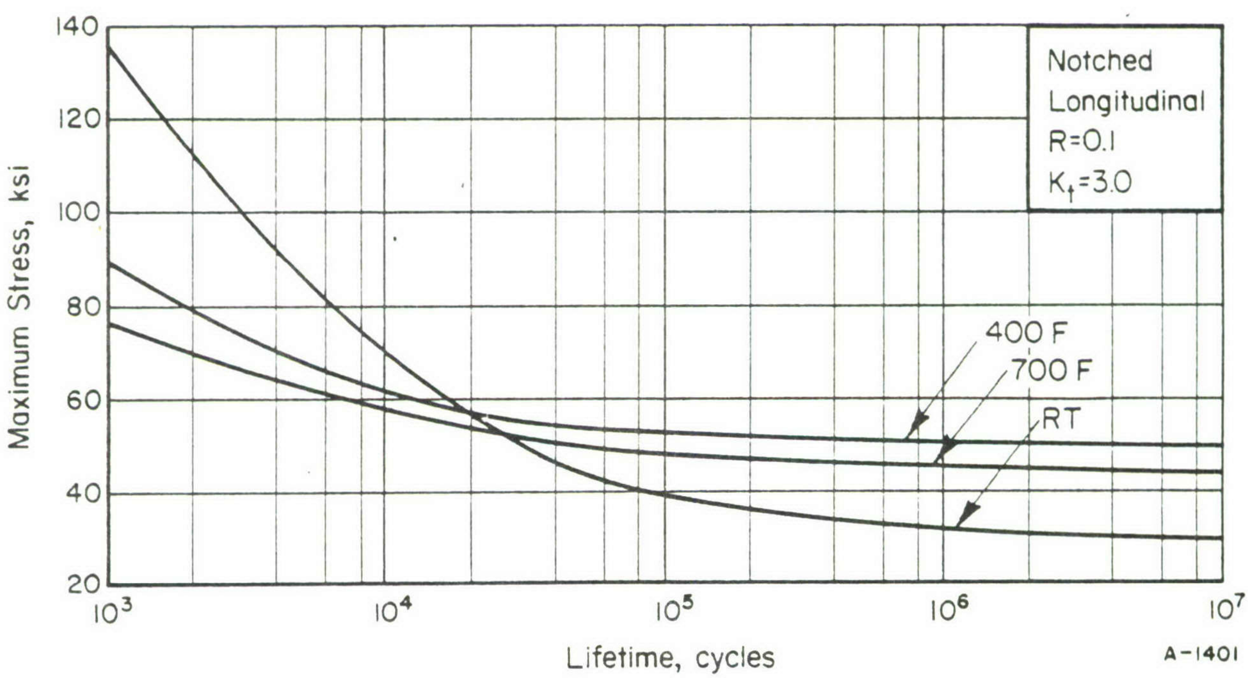


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 17-4 PH (H900) BAR (ESR)

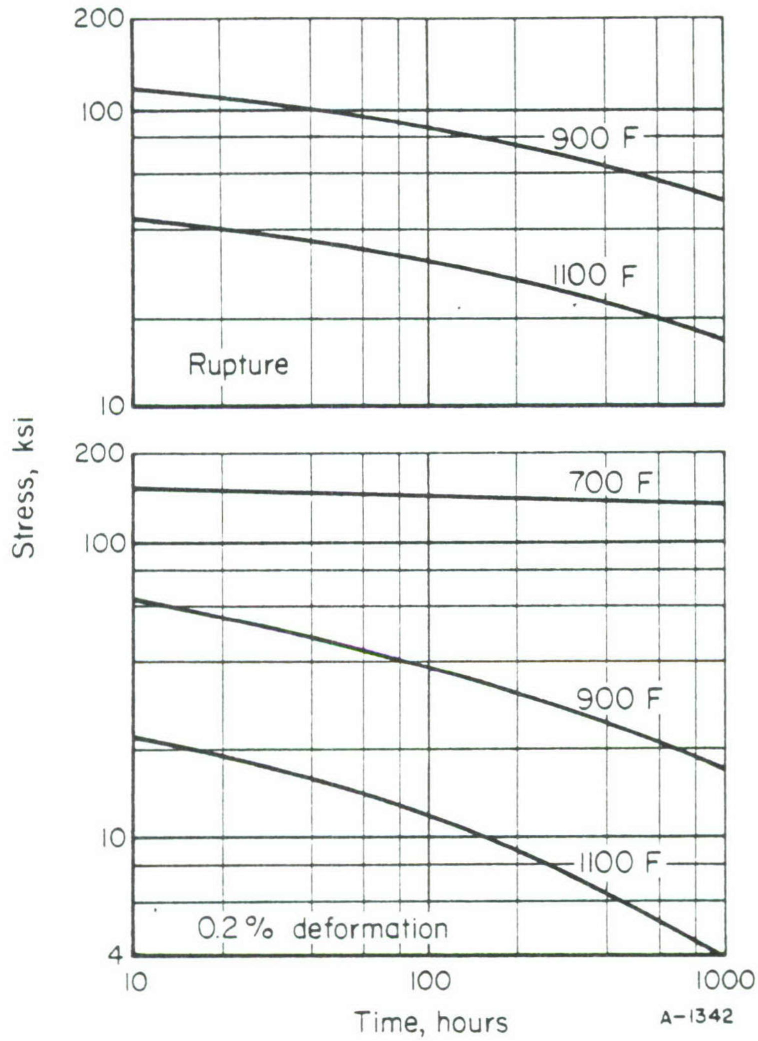


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 17-4 PH (H900) BAR (ESR)

Udimet 710 Forged Bar

Material Description

Udimet 710 was recently developed by Special Metals Corporation to fill the need for a jet engine turbine blading alloy, combining the high strength and stability characteristics of Udimet 700 with the corrosion and sulfidation resistance of 18% chromium alloys such as the older Udimet 500 and Waspaloy. The alloy is designed for use in either the wrought or cast form. Data generated at Special Metals from laboratory heats show it to have rupture strengths superior to Udimet 700, good oxidation and hot corrosion resistance and excellent phase stability after extended exposure to stress and temperature. Data are now being generated from production scale heats for both cast and wrought forms.

The material used for this evaluation was Special Metal Corporation Heat No. 8-2814. The alloy was obtained as 1.875 inch diameter bar with the following composition:

Chemical Composition	Percent
Carbon	0.07
Manganese	0.10
Silicon	0.10
Chromium	18.0
Cobalt	14.8
Iron	0.14
Molybdenum	3.10
Tungsten	1.47
Titanium	4.88
Aluminum	2.51
Boron	0.018
Zirconium	0.04
Sulfur	0.003
Nickel	Balance

Processing and Heat Treating

Heat treatment, as suggested by Special Metals, was as follows:

(1) 2150 F for 4 hours, air cool,

(2) 1975 F for 4 hours, air cool,

(3) 1550 F for 24 hours, air cool,

(4) 1400 F for 16 hours, air cool.

UDIMET 710 Alloy Data[a]

Condition: Solution Treated and Aged
Product: 1.875-inch forged bar

Properties	RT	800	1200	1800
	Temperature, F			
Tension				
TUS (longitudinal), ksi	177.7	166.1	183.9	55.0
TYS (longitudinal), ksi	138.0	122.8	122.9	37.0
e (longitudinal), percent in 2 in.	7.2	7.6	15.3	30.0
RA (longitudinal), percent	8.7	9.2	14.6	35.3
E (longitudinal), 10^3 psi	29.2	24.2	20.9	18.8
Compression				
CYS (longitudinal), ksi	149.7	127.0	118.5	37.3
E_c (longitudinal), 10^3 psi	30.6	25.5	22.5	18.2
Shear[b]				
SUS (longitudinal), ksi	126.3	U[c]	U	U
Impact[d]				
V-notch Charpy, ft. lb. (longitudinal)	27.8	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi $\sqrt{in.}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	160	121	121	U
10^5 cycles, ksi	125	93	93	U
10^7 cycles, ksi	100	50	76	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	139	83	74	U
10^5 cycles, ksi	66	47	44	U
10^7 cycles, ksi	27	27	40	U

Properties	RT	Temperature, F 1000	1400	1800
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	130	39	<1
0.2% plastic deformation, 1000 hr, ksi	NA	121	30	<1
Stress Rupture (long transverse)				
Rupture, 100 hr, ksi	NA	167	65	8
Rupture, 1000 hr, ksi	NA	160	52	2
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
8.7×10^{-6} in./in./F (70 to 1400 F)				
Density				
0.292 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Four longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 79.4 ksi$\sqrt{\text{in.}}$ Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, this K_Q value is <u>not</u> a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

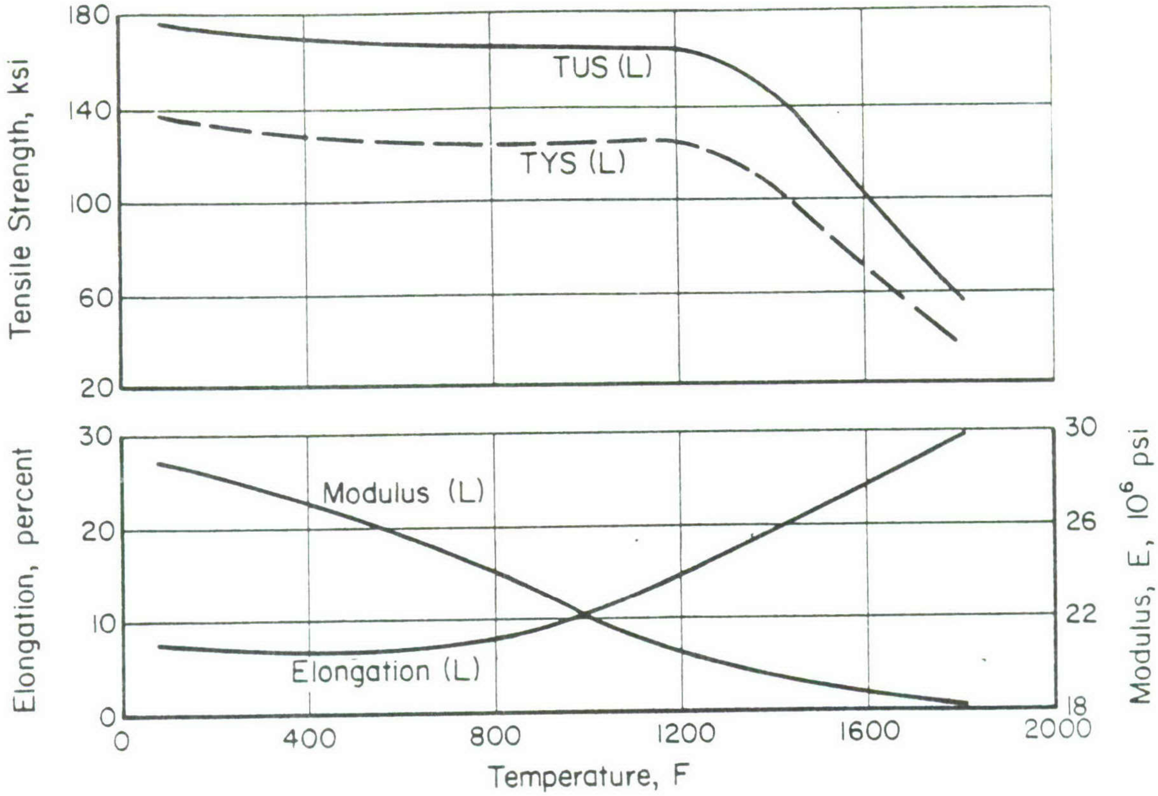


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF UDIMET 710 FORGED BAR

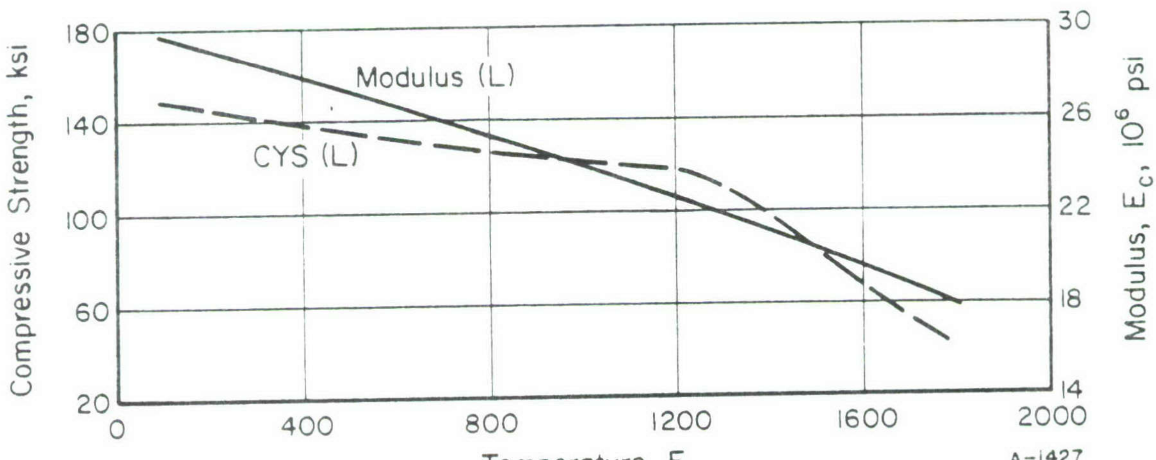


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF UDIMET 710 FORGED BAR

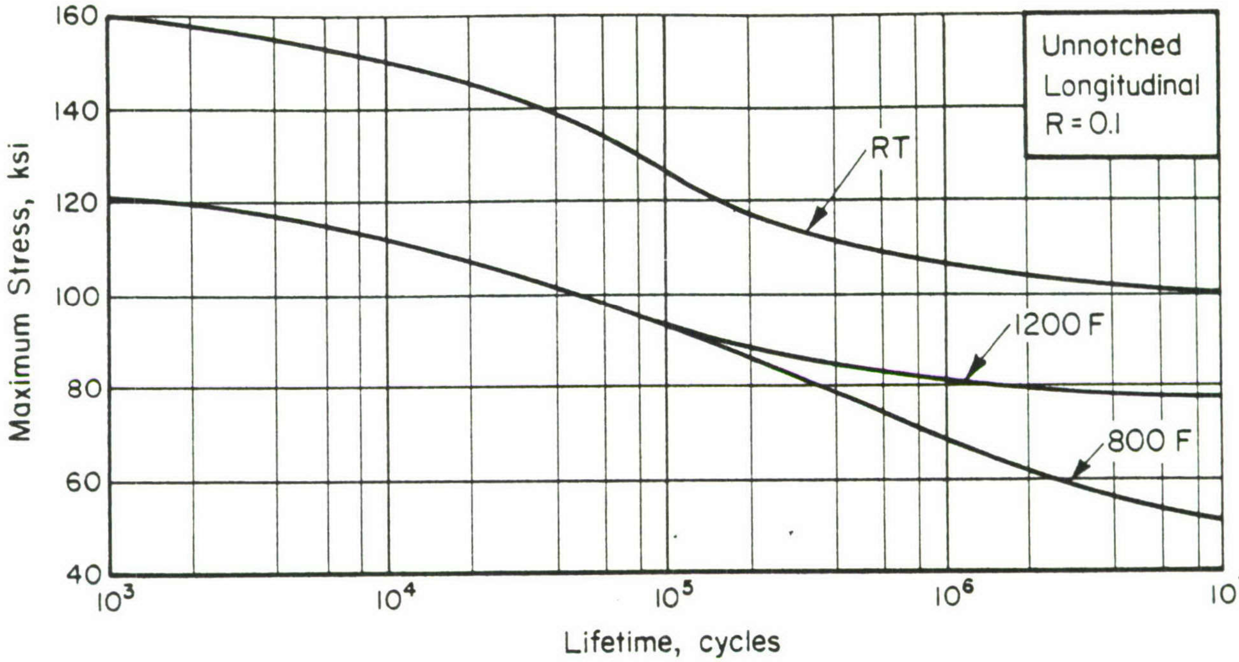


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED UDIMET 710 FORGED BAR

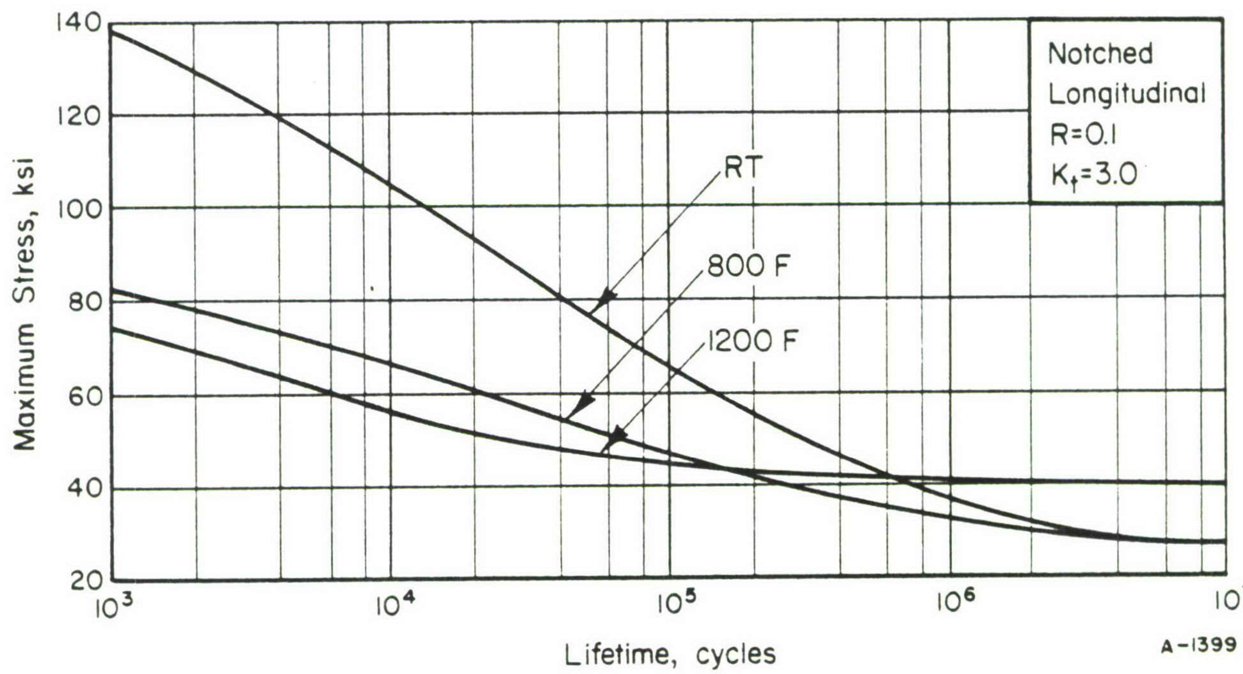


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) UDIMET 710 FORGED BAR

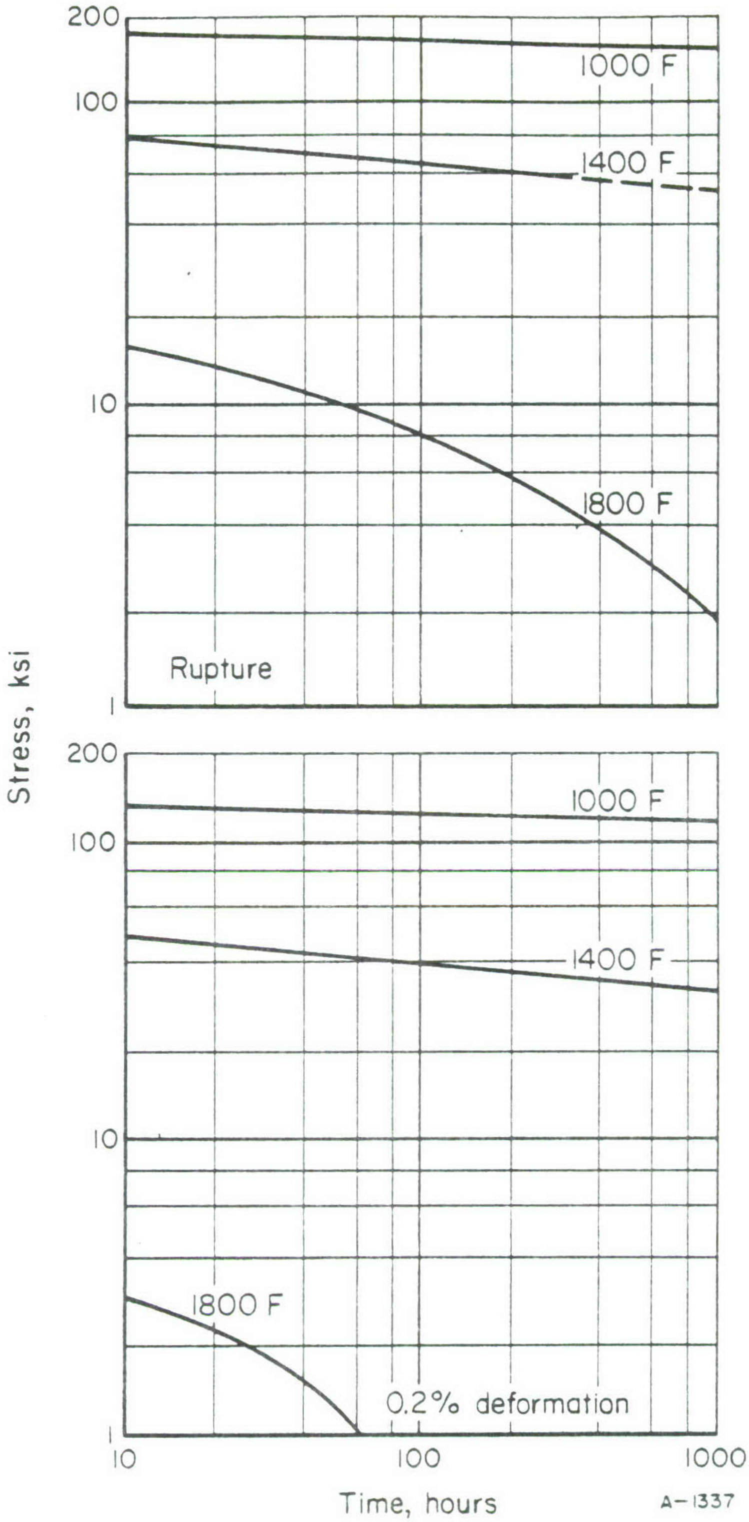


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR UDIMET 710 FORGED BAR

7050-T7E56 Hand Forging

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliatiation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used for this evaluation was a 5-inch by 10-inch by 5-foot hand forging produced within the following composition limits:

Chemical Composition	Percent
Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance

Processing and Heat Treating

The specimens were tested in the as-received -T7E56 temper.

7050-T7E56 Aluminum Alloy Data[a]

Thickness: 5-inch x 10-inch hand forging

Properties	Temperature, F RT	250	350	500
Tension				
TUS (longitudinal), ksi	73.8	57.3	47.1	18.6
TUS (transverse), ksi	71.1	57.4	45.5	19.4
TUS (short transverse), ksi	72.1	U[c]	U	U
TYS (longitudinal), ksi	63.9	55.4	46.3	18.4
TYS (transverse), ksi	62.1	55.2	44.0	18.7
TYS (short transverse), ksi	58.9	U	U	U
e (longitudinal), percent in 2 in.	15.3	16.2	15.3	28.7
e (transverse), percent in 2 in.	5.7	15.8	16.0	25.2
e (short transverse), percent in 2 in.	6.3	U	U	U
RA (longitudinal), percent	39.2	47.9	61.9	82.5
RA (transverse), percent	7.8	35.5	46.7	80.8
RA (short transverse), percent	7.9	U	U	U
E (longitudinal), 10^6 psi	9.9	9.5	8.3	8.3
E (transverse), 10^6 psi	9.9	9.4	8.4	7.9
E (short transverse), 10^6 psi	9.8	U	U	U
Compression				
CYS (longitudinal), ksi	68.5	61.3	50.4	21.2
CYS (transverse), ksi	65.6	58.9	49.5	21.5
E_c (longitudinal), 10^6 psi	10.7	9.9	9.2	7.3
E_c (transverse), 10^6 psi	11.4	9.7	9.1	7.0
Shear[b]				
SUS (longitudinal), ksi	43.0	U	U	U
SUS (transverse), ksi	41.6	U	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	11.3	U	U	U
(transverse)	2.1	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi$\sqrt{in.}$	(e)	U	U	U
K_{Ic} (transverse), ksi$\sqrt{in.}$	28.8	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	53	49	42	U
10^5 cycles, ksi	42	30	24	U
10^7 cycles, ksi	30	22	18	U

Properties	RT	Temperature, F 250	350	500
Axial Fatigue (transverse) (continued)				
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	50	50	43	U
10^5 cycles, ksi	21	21	17	U
10^7 cycles, ksi	12	12	12	U
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	40	16	3.5
0.2% plastic deformation, 1000 hr, ksi	NA	35	11	2.1
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	45	22	6
Rupture, 1000 hr, ksi	NA	38	14	4
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
12.8×10^{-6} in./in./F (68 to 212 F)				
Density				
0.102 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Four longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 62.6 ksi$\sqrt{\text{in.}}$ Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length for longitudinal tests, this K_Q value is not a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

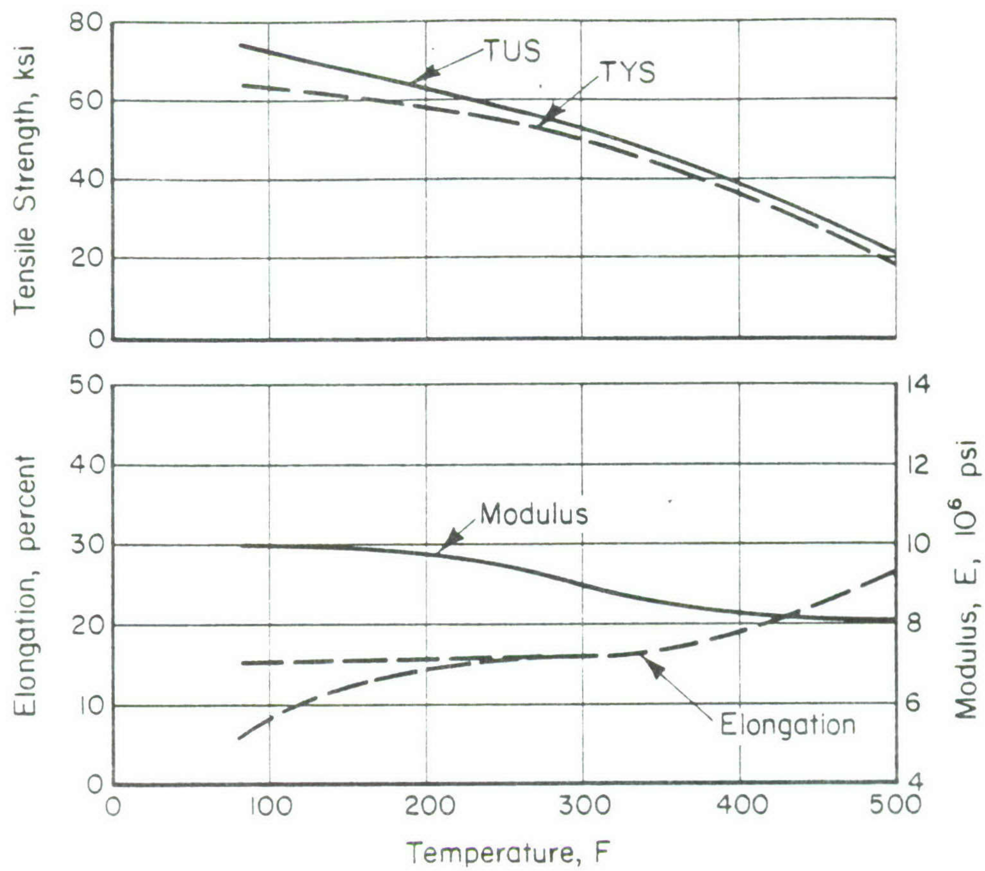


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T7E56 HAND FORGING

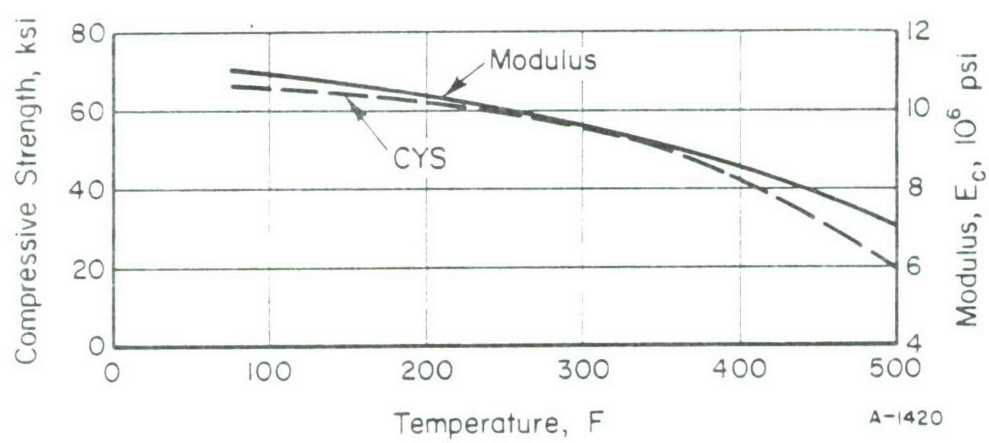


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T7E56 HAND FORGING

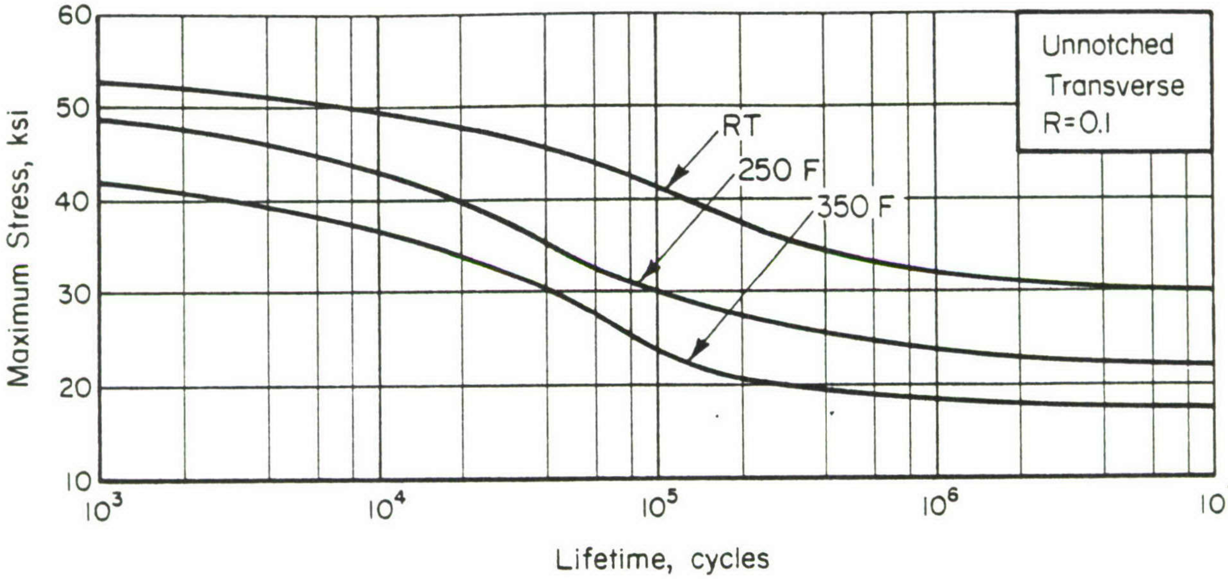


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 7050-T7E56 HAND FORGING

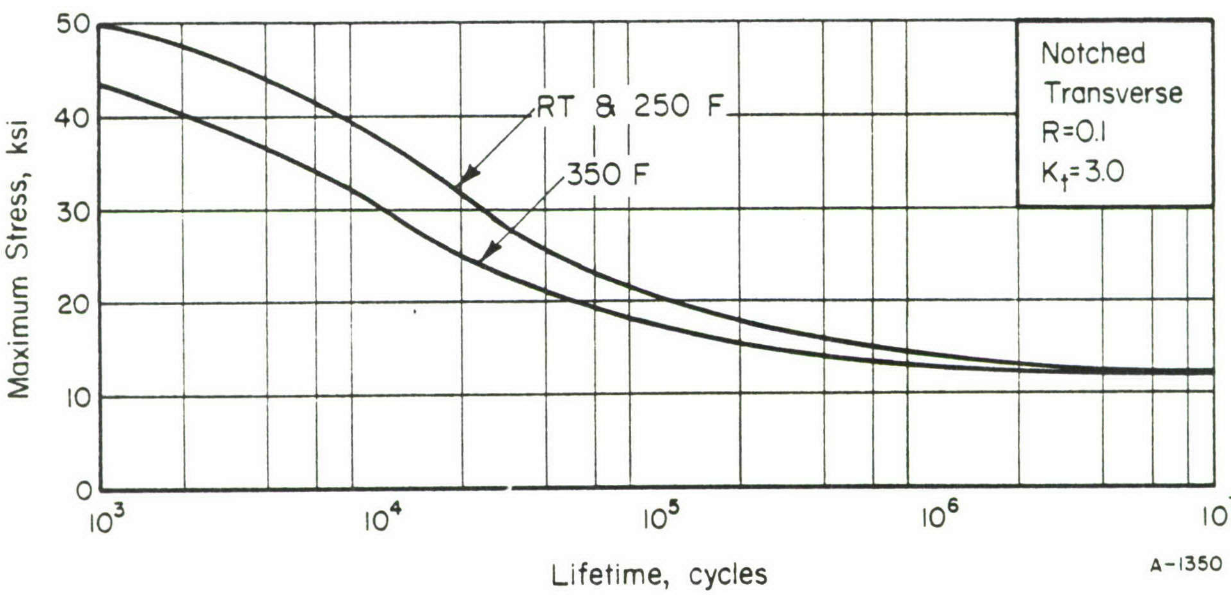


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t= 3.0) 7050-T7E56 HAND FORGING

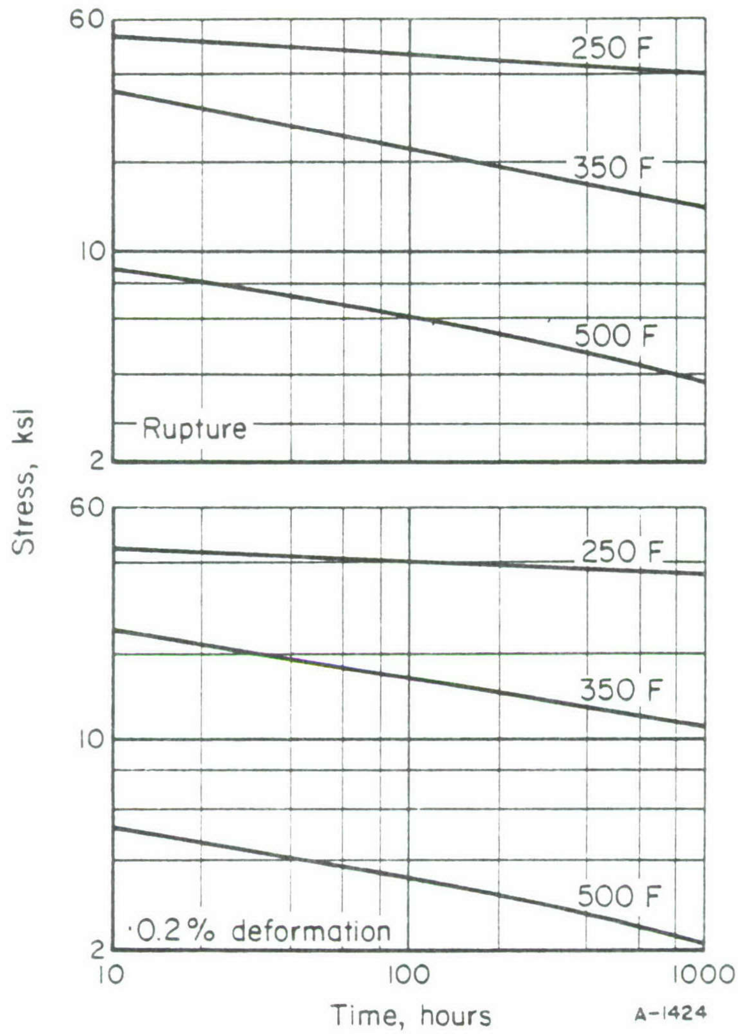


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7050-T7E56 HAND FORGING (TRANSVERSE)

2214-T351 Plate (Alcoa 417 Process)

Material Description

Alloy 2214 is a high-purity version of 2014 with closer controls on iron and silicon (Alcoa 417 process). The Alcoa 417 process, which utilizes only hot rolling and special controls during all stages of fabrication, is a more economic means for achieving the required properties without adversely influencing the overall engineering characteristics of the material. The material used in this evaluation was obtained from Alcoa as a 2-1/4-inch-thick plate within the following composition limits:

Chemical Composition	Percent
Silicon	0.50 to 1.2
Iron	0.3 max
Copper	3.9 to 5.0
Manganese	0.40 to 1.2
Magnesium	0.20 to 0.80
Chromium	0.10 max
Zinc	0.25 max
Titanium	0.15
Others	0.15 max
Aluminum	Balance

Processing and Heat Treating

Specimens were tested in the as-received -T351 temper.

2214-T351 Aluminum Alloy Data[a]

Thickness: 2 1/4-inch plate

Properties	Temperature, F			
	RT	250	350	500
Tension				
TUS (longitudinal), ksi	64.9	56.1	51.7	26.1
TUS (transverse), ksi	66.0	57.2	53.2	26.8
TYS (longitudinal), ksi	46.8	41.8	37.6	19.7
TYS (transverse), ksi	42.7	38.4	35.9	18.4
e (longitudinal), percent in 2 in.	23.8	22.3	24.2	25.0
e (transverse), percent in 2 in.	21.0	23.8	21.0	21.5
RA (longitudinal), percent	34.2	39.7	60.9	71.5
RA (transverse), percent	27.6	33.5	41.9	64.3
E (longitudinal), 10^6 psi	10.5	9.9	9.4	8.0
E (transverse), 10^6 psi	10.5	9.8	9.1	7.9
Compression				
CYS (longitudinal), ksi	37.7	35.6	31.9	25.1
CYS (transverse), ksi	44.6	39.9	35.3	25.5
E_c (longitudinal), 10^6 psi	10.7	9.9	9.0	7.1
E_c (transverse), 10^6 psi	10.5	10.0	8.8	7.1
Shear[b]				
SUS (longitudinal), ksi	40.0	U[c]	U	U
SUS (transverse), ksi	36.9	U	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	5.1	U	U	U
(transverse)	1.9	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi$\sqrt{\text{in.}}$	(e)	U	U	U
K_{Ic} (transverse), ksi$\sqrt{\text{in.}}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	68	59	59	U
10^5 cycles, ksi	50	39	39	U
10^7 cycles, ksi	38	26	30	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	47	43	43	U
10^5 cycles, ksi	24	21	21	U
10^7 cycles, ksi	16	11	14	U

2214-T351 Aluminum Alloy Data (continued)

Properties	Temperature, F RT	250	350	500
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	37	13	2
0.2% plastic deformation, 1000 hr, ksi	NA	22	7	1
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	45	18	5
Rupture, 1000 hr, ksi	NA	39	13	3.5
Stress Corrosion[(g)]				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
13.5×10^{-6} in./in./F (68 to 500 F)				
Density				
0.101 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 4 tests.

(e) Six longitudinal and 6 transverse slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. Average K_Q obtained was 45 ksi $\sqrt{in.}$ in the longitudinal direction and 50.8 ksi $\sqrt{in.}$ in the transverse direction. Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, this K_Q value is not a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

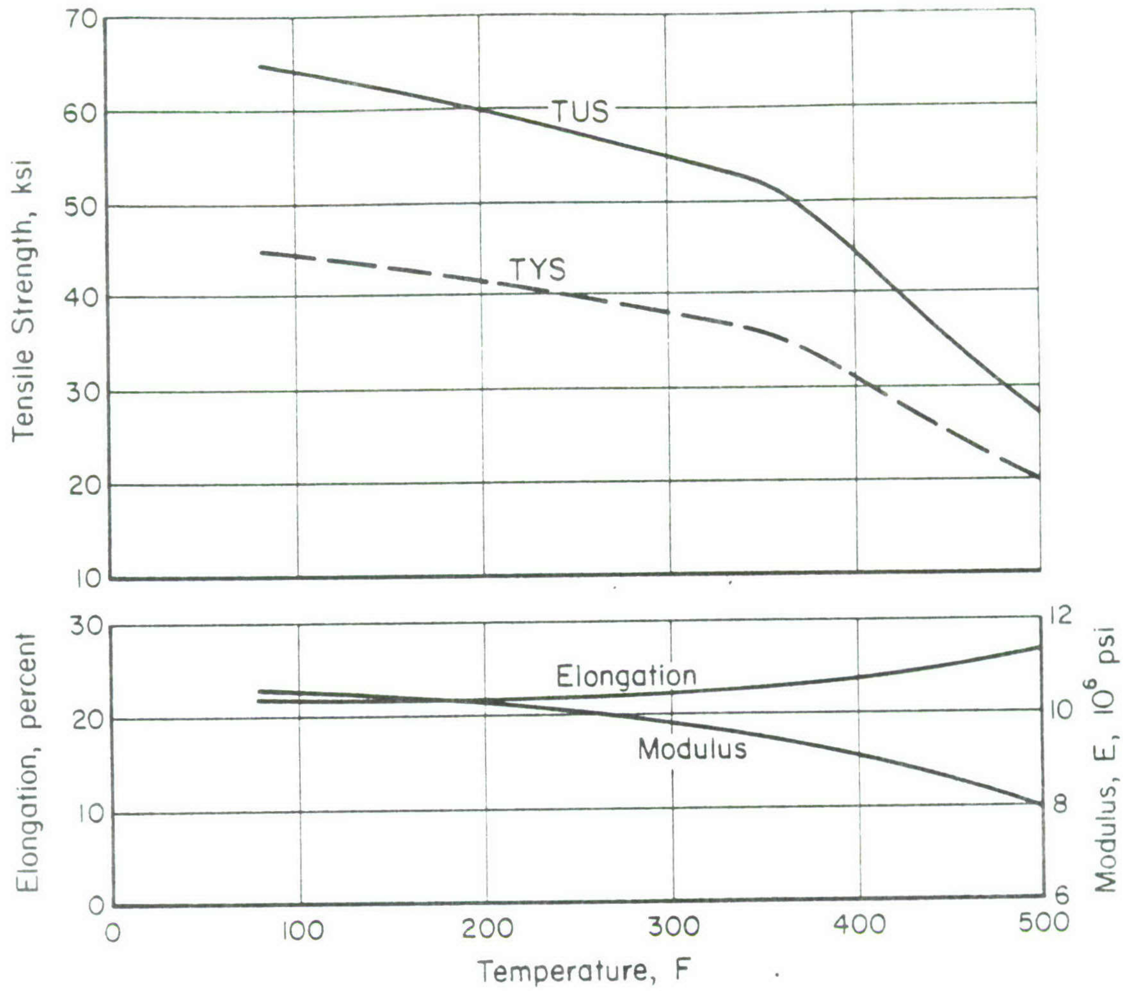


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 2214-T351 PLATE

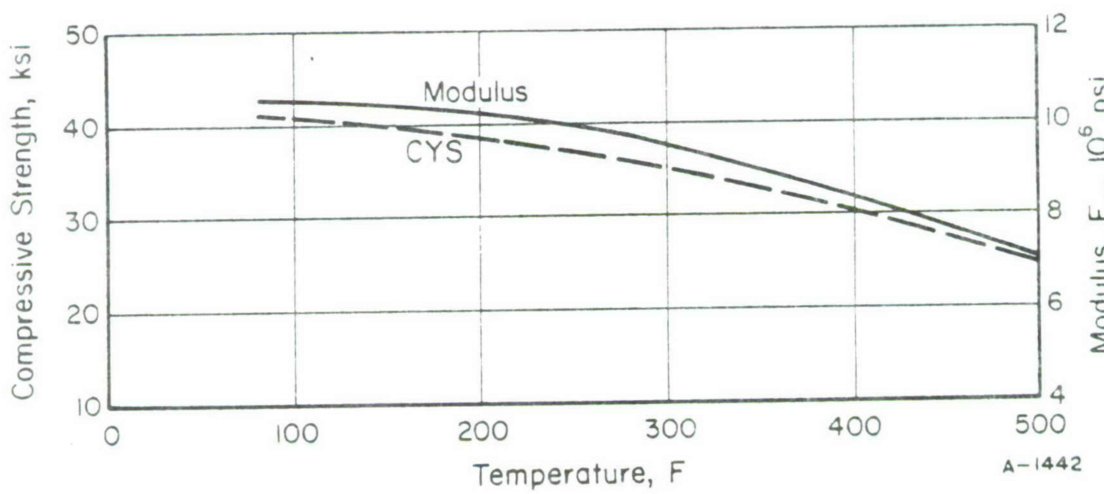


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 2214-T351 PLATE

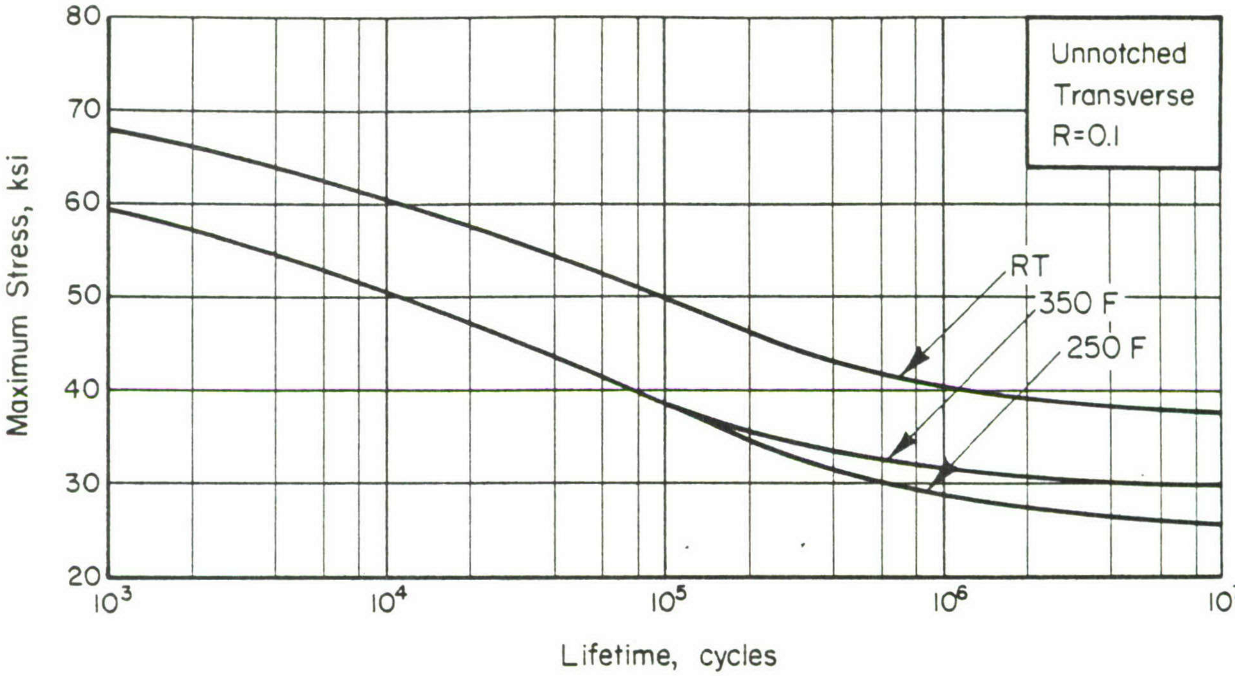


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 2214-T351 PLATE

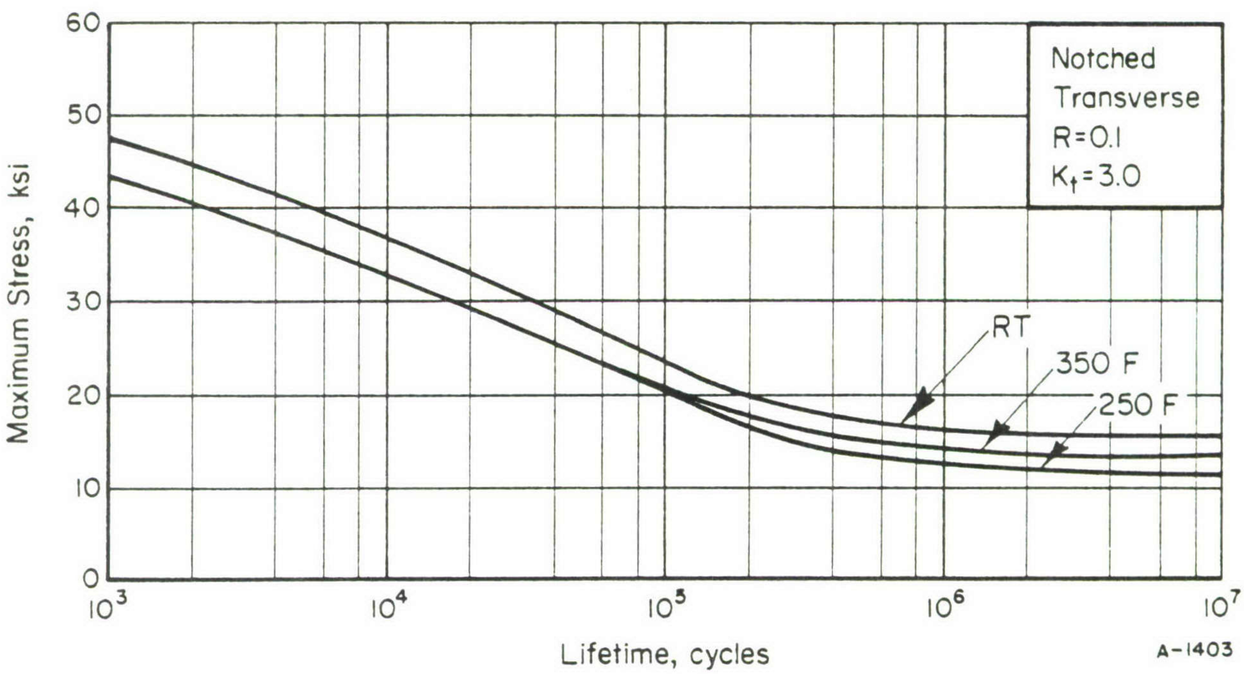


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 2214-T351 PLATE

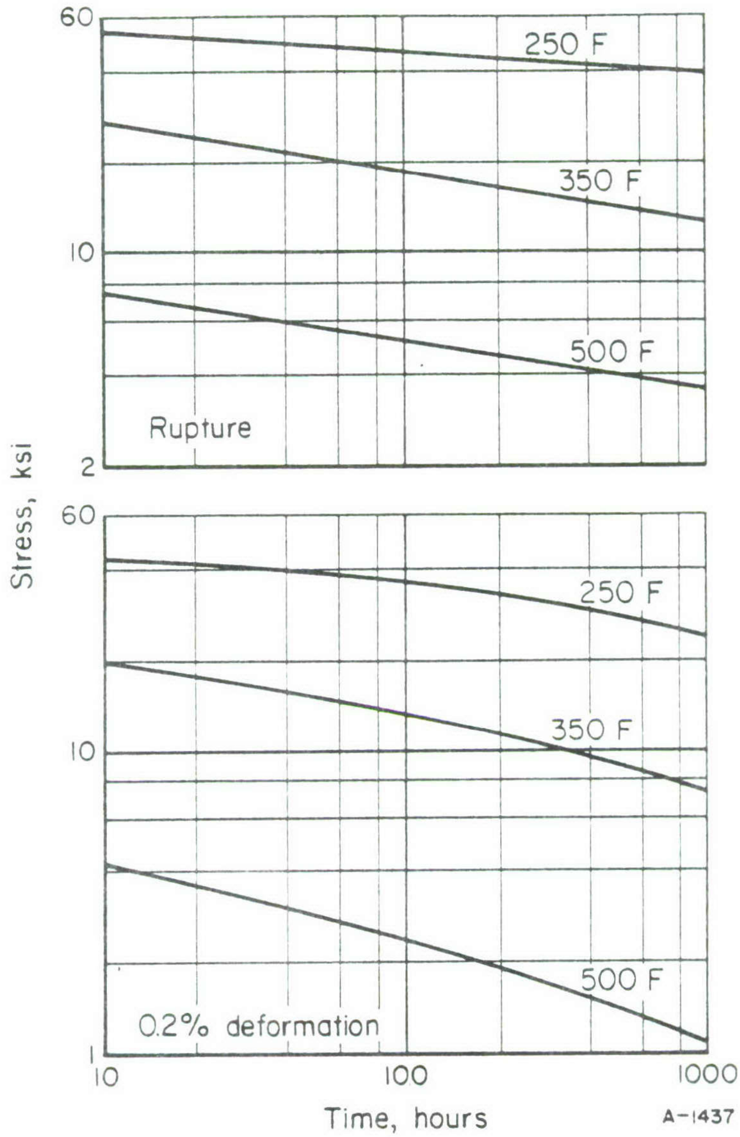


FIGURE 5. STRESS-RUPTURE AND ELASTIC DEFORMATION CURVES FOR 2214-T351 PLATE (TRANSVERSE)

Ti-6Al-4V Diffusion Bonded Component (DBHT)

Material Description

The material for this evaluation was supplied by the Air Force Materials Laboratory and consisted of pieces sectioned from a helicopter rotor hub. The rotor hub had been formed by diffusion bonding of 1/2-inch-thick Ti-6Al-4V plate. The evaluation material consisted of sections of the hub and lug ends. The material was tested in the as-received (diffusion bonded heat treated)(DBHT) condition.

Ti-6Al-4V Data[a]

Condition: Diffusion bonding heat treatment
Product: Diffusion bonded component

Properties	RT	400	500	700	900
	Temperature, F				
Tension					
TUS (transverse), ksi	151.3	123.3	U	107.0	94.4
TYS (transverse), ksi	143.3	109.3	U	88.7	80.9
e (transverse), percent in 2 in.	11.2	11.8	U	8.8	17.0
E (transverse), 10^6 psi	15.9	14.5	U	12.5	11.0
Compression					
CYS (transverse), ksi	146.3	111.3	U	97.1	92.8
E_c (transverse), 10^6 psi	17.9	16.6	U	15.5	14.5
Shear[b]					
SUS (longitudinal), ksi	92.5	U[c]	U	U	U
SUS (transverse), ksi	92.8	U	U	U	U
Impact[d]					
V-notch Charpy, ft. lb.					
(longitudinal)	14.2	U	U	U	U
(transverse)	13.2	U	U	U	U
Fracture Toughness					
K_{Ic} (longitudinal), ksi$\sqrt{in.}$	(e)	U	U	U	U
K_{Ic} (transverse), ksi$\sqrt{in.}$	(e)	U	U	U	U
Axial Fatigue (transverse)[f]					
Unnotched, R = 0.1					
10^3 cycles, ksi	125	125	U	98	U
10^5 cycles, ksi	87	87	U	77	U
10^7 cycles, ksi	60	60	U	54	U
Notched, K_t = 3.0, R = 0.1					
10^3 cycles, ksi	102	95	U	95	U
10^5 cycles, ksi	54	47	U	47	U
10^7 cycles, ksi	40	30	U	30	U

Ti-6Al-4V Data (continued)

Properties	RT	400	500	700	900
	Temperature, F				
Creep (transverse)					
0.2% plastic deformation, 100 hr, ksi	NA	U	101	65	11
0.2% plastic deformation, 1000 hr, ksi	NA	U	100	50	6
Stress Rupture (transverse)					
Rupture, 100 hr, ksi	NA	U	111	102	56
Rupture, 1000 hr, ksi	NA	U	110	100	35
Stress Corrosion[(g)]					
80% TYS, 1000 hr maximum	no cracks				
Coefficient of Thermal Expansion					
5.7×10^{-6} in./in./F (68 to 900 F)					
Density					
0.160 lb./in.^{3}					

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen.

(c) U, unavailable; NA, not applicable.

(d) Average of 4 tests.

(e) Quantity of material insufficient for fracture toughness tests.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

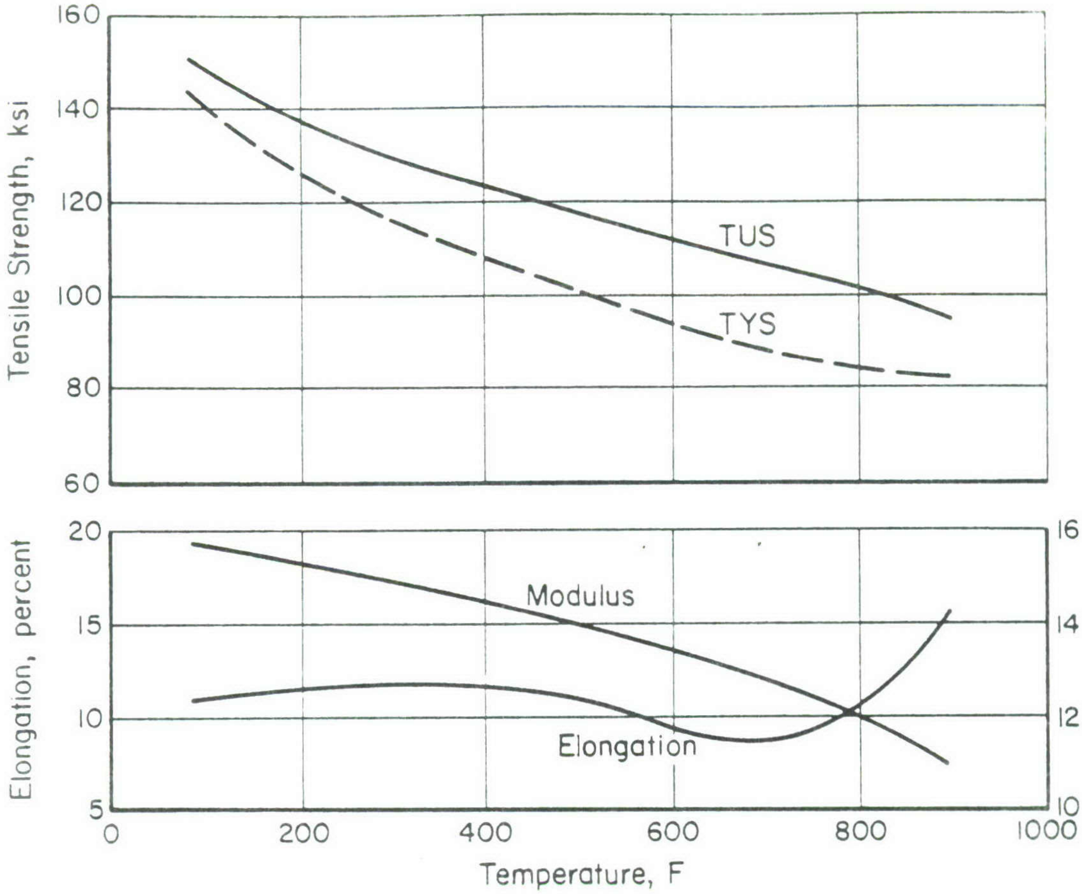


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V DBC (DBHT)

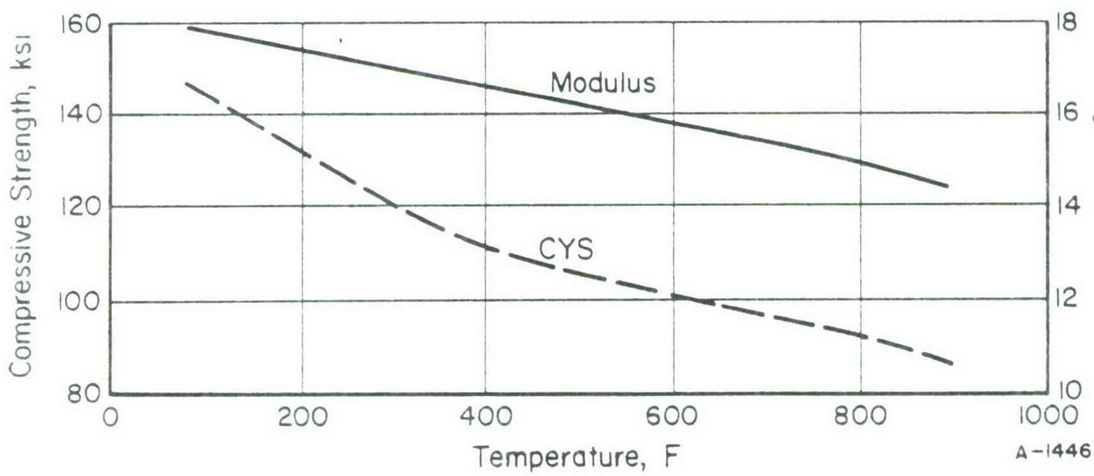


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V DBC (DBHT)

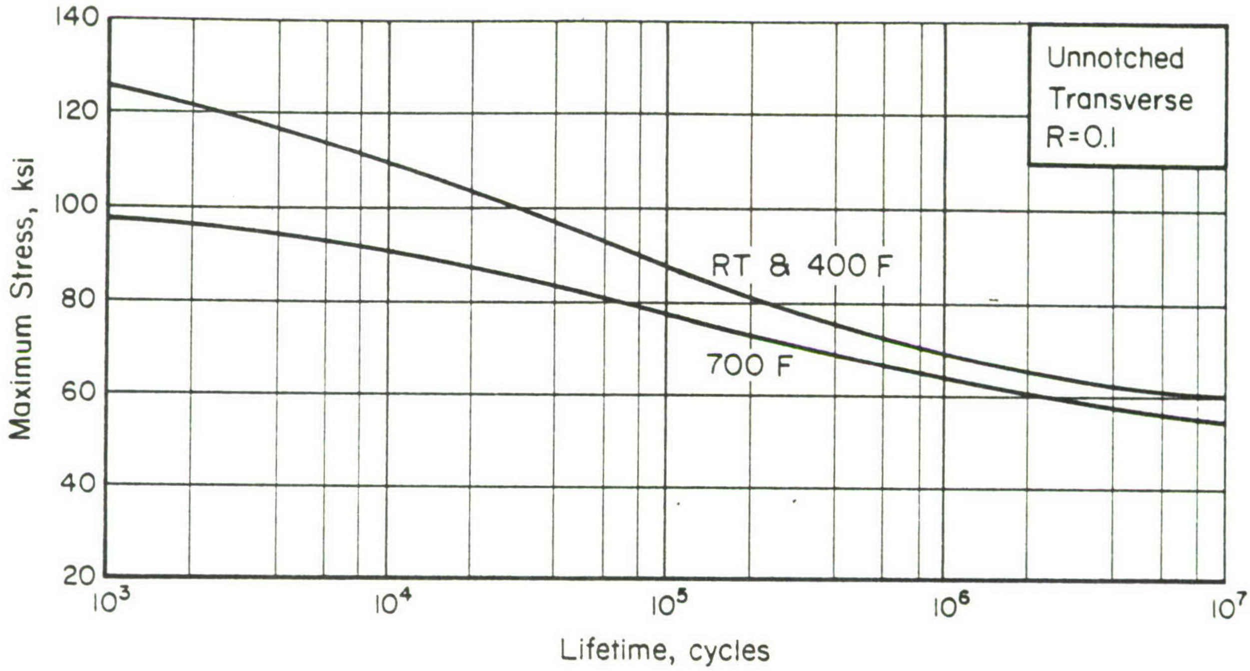


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED Ti-6Al-4V DBC (DBHT)

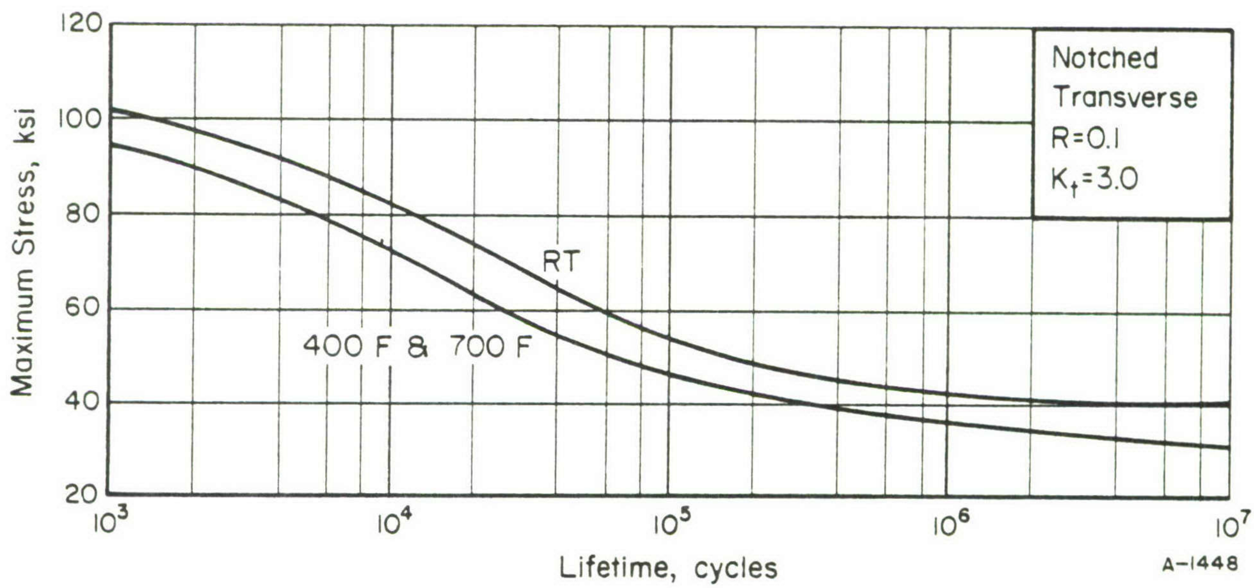


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t= 3.0) Ti-6Al-4V DBC (DBHT)

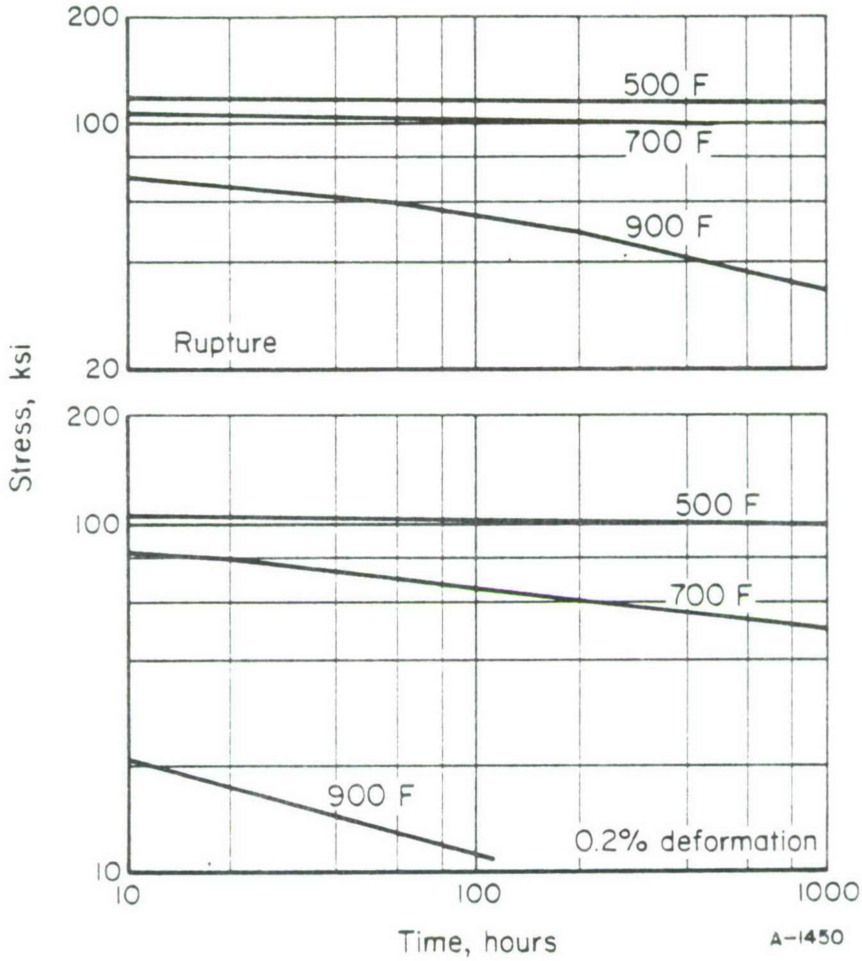


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V DBC (DBHT)

15-5 PH Stainless Steel

15-5 PH is a precipitation-hardening stainless steel that offers a combination of high strength and hardness, excellent corrosion resistance plus good transverse toughness and good forgeability. It is produced by consumable vacuum arc remelting and is virtually "ferrite free".

Fabrication practices for 15-5 PH are generally the same as those established for 17-4 PH. Most techniques are similar to those recommended for the regular grades of stainless steel. Hardening heat treatments require temperatures of only 900 F to 1150 F, depending on the properties desired. Because of the comparatively low hardening temperatures scaling and distortion difficulties are essentially eliminated.

15-5 PH is available in the form of billets, plate, bar, and wire. Typical applications include forgings, pump and valve parts for high pressure systems, aircraft components, and hollow bar parts for hydraulic actuators and controls.

The chemical composition of the forging used for this evaluation is as follows:

Chemical Composition	Percent
Carbon	.037
Manganese	.31
Phosphorus	.018
Sulfur	.010
Silicon	.30
Chromium	15.14
Nickel	4.58
Copper	3.32
Columbium	.24
Tantalum	.01
Iron	Balance

The material tested was obtained from Armco Heat 4W0370 in the form of 2-1/8 inch x 5-3/4 inch x 8 foot forged bar.

Processing and Heat Treating

Specimens were machined in the as-received Condition A followed by heat treatment for 4 hours at 1025 F to Condition H1025.

15-5 PH Stainless Steel Data[a]

Condition: H 1025
Thickness: 2 inch x 6 inch forged bar

Properties	Temperature, F RT	400	700	900
Tension				
TUS (longitudinal), ksi	164.3	147.0	137.3	119.3
TUS (transverse), ksi	164.0	146.7	136.0	118.6
TYS (longitudinal), ksi	163.6	140.3	128.3	111.0
TYS (transverse), ksi	161.6	140.3	127.0	110.0
e (longitudinal), percent in 2 in.	15.3	12.2	10.6	14.7
e (transverse), percent in 2 in.	13.0	10.7	9.2	13.5
RA (longitudinal), percent	63	50	45	59
RA (transverse), percent	51	43	38	51
E (longitudinal), 10^6 psi	30.6	27.7	27.0	22.2
E (transverse), 10^6 psi	28.8	28.2	25.1	23.2
Compression				
CYS (longitudinal), ksi	163.6	144.6	130.0	111.6
CYS (transverse), ksi	165.3	144.0	130.0	111.0
E_c (longitudinal), 10^6 psi	30.2	28.8	27.7	24.4
E_c (transverse), 10^6 psi	30.3	28.9	28.1	24.6
Shear[b]				
SUS (longitudinal), ksi	105.5	U[c]	U	U
SUS (transverse), ksi	104.3	U	U	U
Impact[d]				
V-notch Charpy, ft.lb. (longitudinal)	80.7	U	U	U
V-notch Charpy, ft.lb. (transverse)	40.7	U	U	U
Fracture Toughness				
K_{Ic}, ksi$\sqrt{in}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	172	164	140	U
10^5 cycles, ksi	157	130	113	U
10^7 cycles, ksi	133	120	110	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	142	130	113	U
10^5 cycles, ksi	71	71	68	U
10^7 cycles, ksi	50	60	55	U

15-5 PH Stainless Steel Data
(continued)

Properties	RT	Temperature, F 700	900	1100
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	100	59	12
0.2% plastic deformation, 1000 hr, ksi	NA	87	41	7.5
Stress-Rupture (transverse)				
Rupture, 100 hr, ksi	NA	127	86	33
Rupture, 1000 hr, ksi	NA	123	69	18
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
6.7×10^{-6} in/in/F (70 to 400F)				
6.7×10^{-6} in/in/F (70 to 900F)				
Density				
0.283 lb/in^3				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Six longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 191.0 ksi$\sqrt{in.}$ Since the size ratio, $2.5\ (K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, this K_Q value is not a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

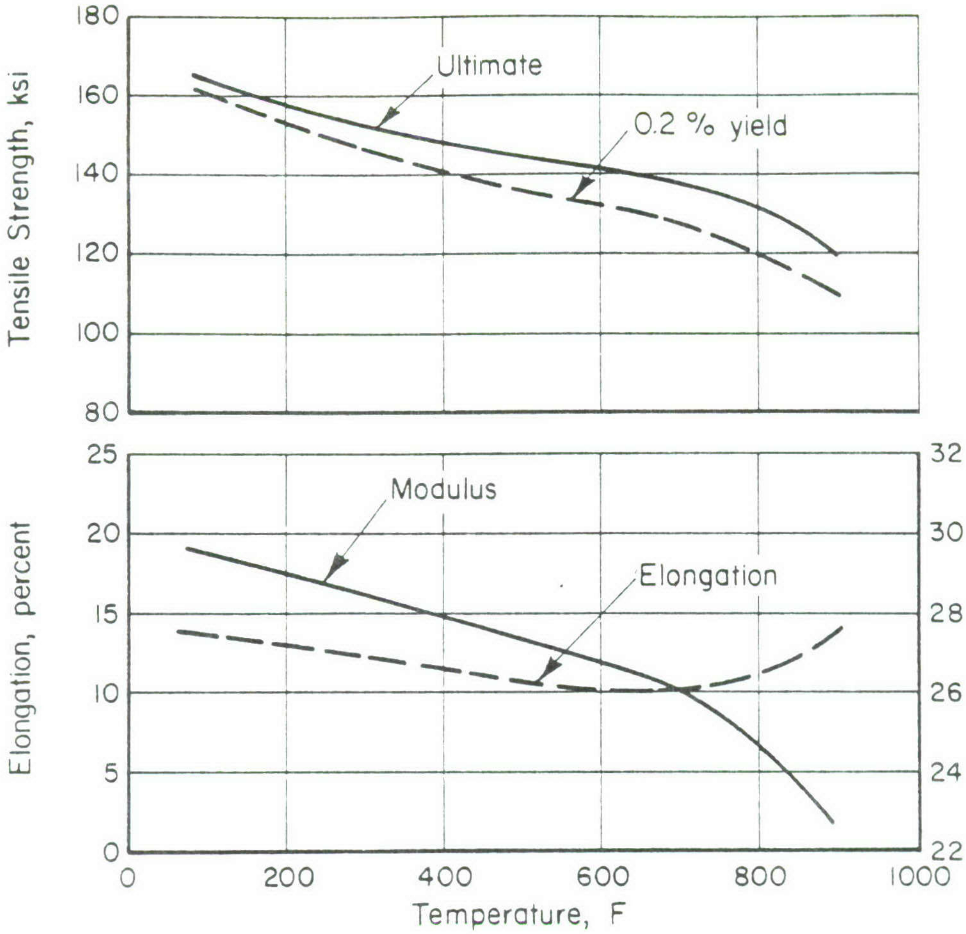


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 15-5 PH (H1025) FORGED BAR

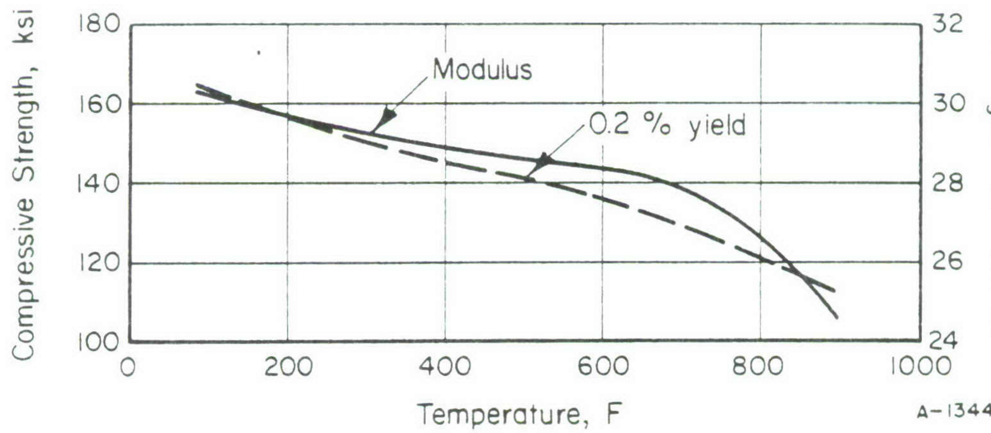


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 15-5 PH (H1025) FORGED BAR

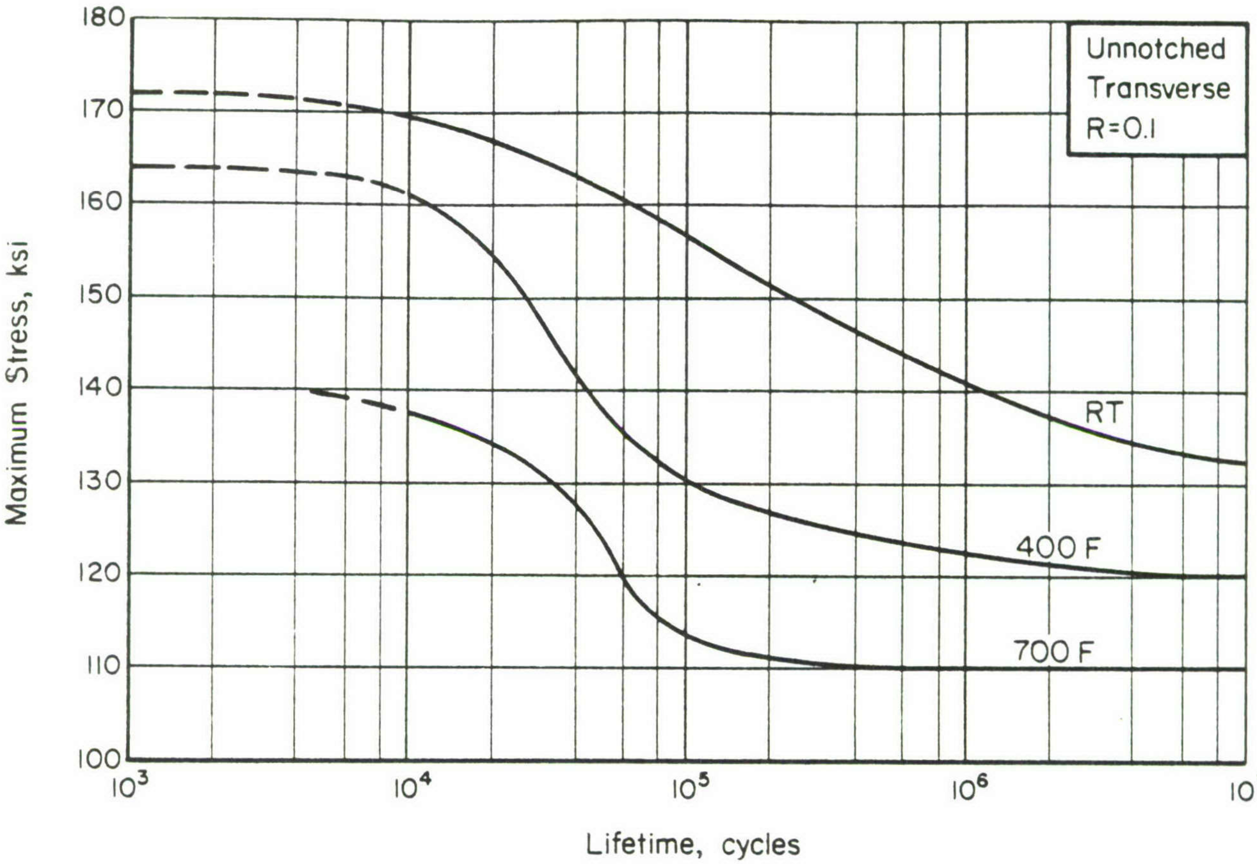


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR FOR UNNOTCHED 15-5 PH (H1025) FORGED BAR

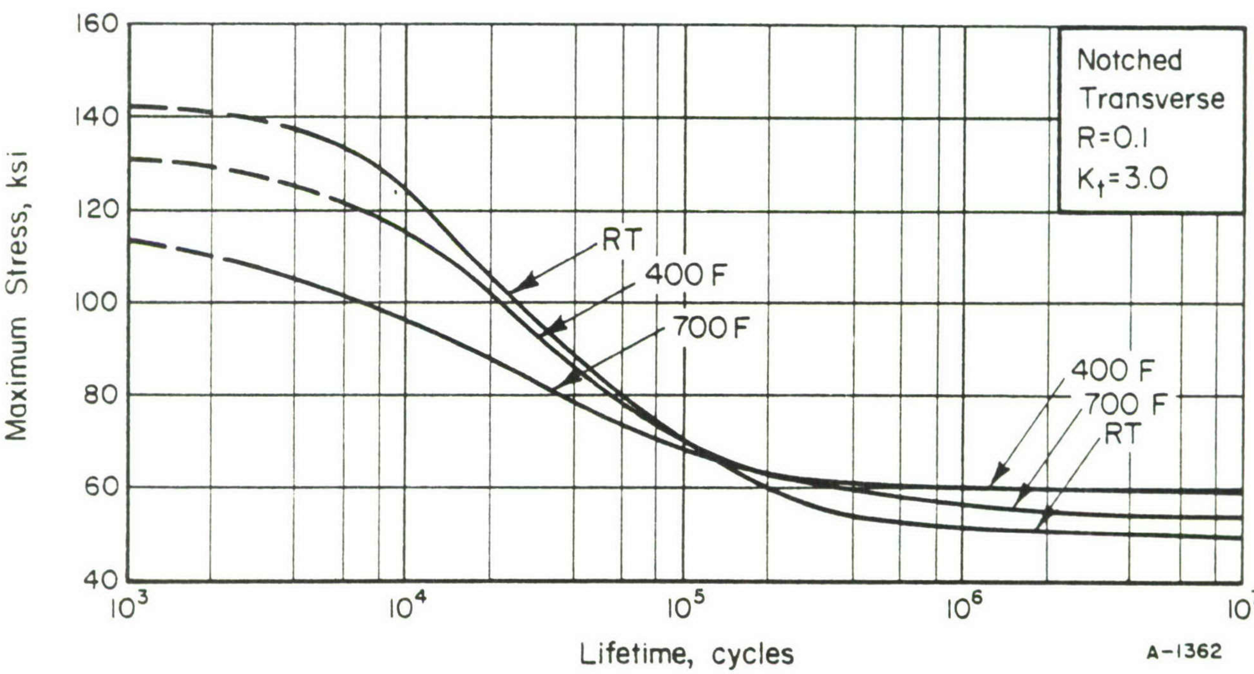


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR FOR NOTCHED (K_t = 3.0) 15-5 PH (H1025) FORGED BAR

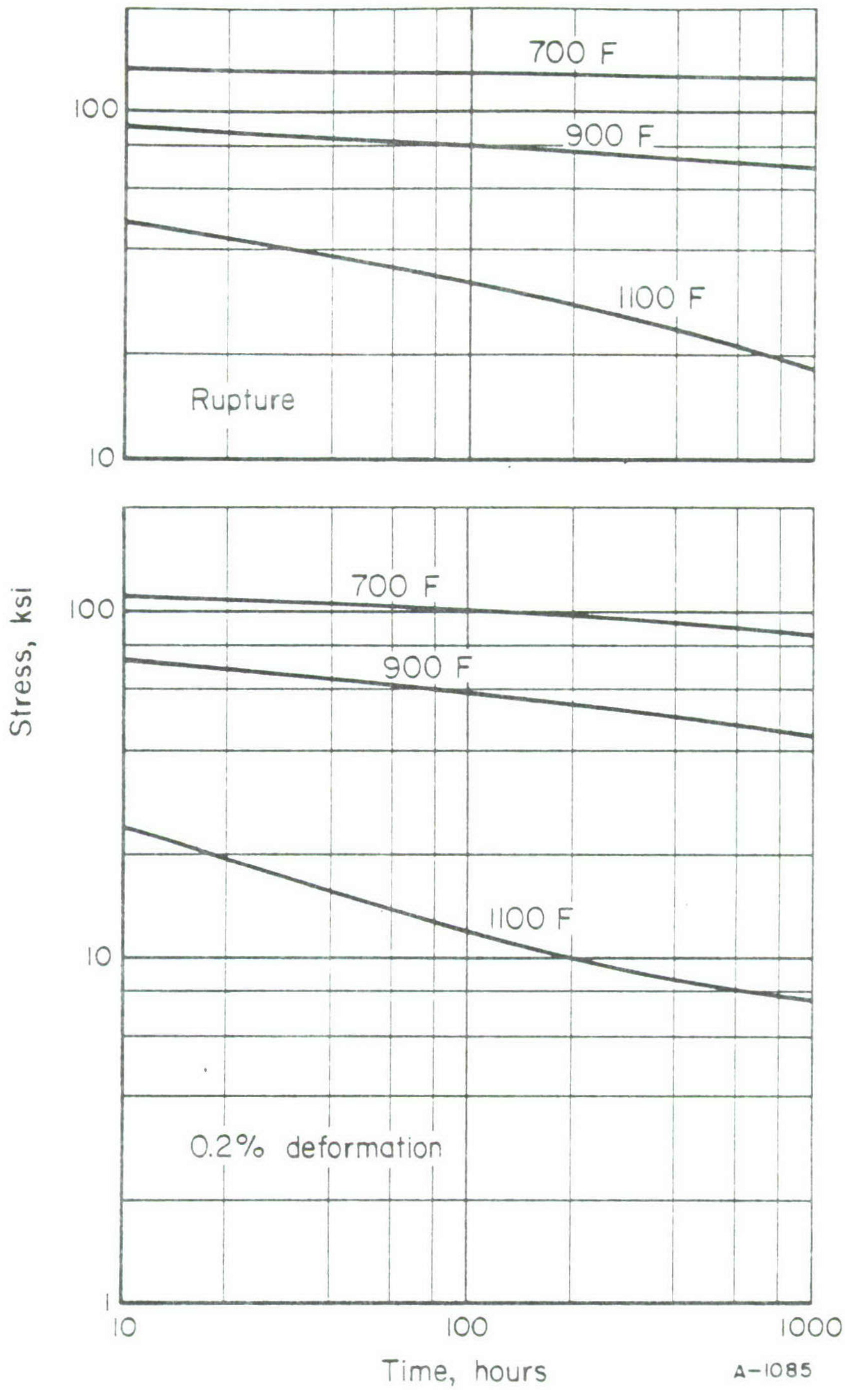


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 15-5 PH (H1025) FORGED BAR (TRANSVERSE)

HP 9Ni-4Co-0.20C Alloy Steel

Material Description

HP 9Ni-4Co-0.20C steel was developed specifically to have high hardenability combined with good fracture toughness. It can be welded in the fully heat-treated condition and achieve essentially 100 percent joint efficiency without preheat or postheat treatment. The 0.20C grade is available as sheet, strip, plate, bars, forgings, and tubing.

The material used for this program was consumable electrode vacuum melted and from Republic Steel Heat 3821003. It was obtained as a 2-1/4 inch x 6-inch x 84 inch forged bar and had the following composition:

Chemical Composition	Percent
Carbon	0.19
Manganese	0.36
Phosphorus	0.008
Sulfur	0.007
Silicon	0.04
Nickel	9.30
Chromium	0.80
Molybdenum	1.04
Vanadium	0.08
Cobalt	4.70
Iron	Balance

Processing and Heat Treating

Specimens were rough machined in the as-received annealed condition, heat treated as follows:

(1) normalize at 1650 F, 1 hour, air-cool,

(2) austenitize at 1500 F, 1 hour, oil quench,

(3) single temper at 1025 F, 6 hours, air cool and then finish machined.

HP 9Ni-4Co-0.20C Data[(a)]

Condition: Quenched and Tempered
Thickness: 2 inch x 6 inch forging

Properties	RT	500	700	900
	Temperature, F			
Tension				
TUS (longitudinal), ksi	197.0	179.7	170.3	147.6
TUS (transverse), ksi	197.0	179.0	168.6	147.0
TYS (longitudinal), ksi	180.6	165.0	155.3	129.6
TYS (transverse), ksi	180.0	166.0	152.7	129.0
e (longitudinal), percent in 2-in.	17.5	16.0	16.2	18.0
e (transverse), percent in 2 in.	14.6	14.0	14.5	16.0
RA (longitudinal), percent	68.0	65.5	66.7	69.8
RA (transverse), percent	56.0	55.5	57.8	60.4
E (longitudinal), 10^6 psi	27.0	26.0	24.3	22.0
E (transverse), 10^6 psi	27.3	25.9	24.7	23.8
Compression				
CYS (longitudinal), ksi	196.7	171.6	159.0	135.3
CYS (transverse), ksi	194.6	171.3	158.0	135.6
E_c (longitudinal), 10^6 psi	27.8	26.4	25.1	24.4
E_c (transverse), 10^6 psi	28.0	26.2	25.3	24.0
Shear[(b)]				
SUS (longitudinal), ksi	123.6	U[(c)]	U	U
SUS (transverse), ksi	122.3	U	U	U
Impact[(d)]				
V-notch Charpy, ft./lb.				
(longitudinal)	62	U	U	U
(transverse)	53	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi$\sqrt{in.}$	(e)	U	U	U
K_{Ic} (transverse), ksi$\sqrt{in.}$	(e)	U	U	U
Axial Fatigue (transverse)[(f)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	170	170	170	U
10^5 cycles, ksi	73	101	122	U
10^7 cycles, ksi	57	96	116	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	114	114	114	U
10^5 cycles, ksi	62	42	57	U
10^7 cycles, ksi	60	30	50	U

Properties	Temperature, F RT	500	700	900
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	150	115	60
0.2% plastic deformation, 1000 hr, ksi	NA	149	95	31
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	162	151	95
Rupture, 1000 hr, ksi	NA	159	149	70
Stress Corrosion[(g)]				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
6.4×10^{-6} in./in./F (80 to 900 F)				
Density				
0.284 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 3 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 5 tests.

(e) Three longitudinal and 3 transverse slow-bend specimens were tested. Specimen size was 0.750-inch by 1.500 inches wide with a span of 6 inches. Average K_Q obtained was 161.3 ksi $\sqrt{\text{in.}}$ in the longitudinal direction and 122.9 ksi $\sqrt{\text{in.}}$ in the transverse direction. Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, these values are not valid K_{Ic} values by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

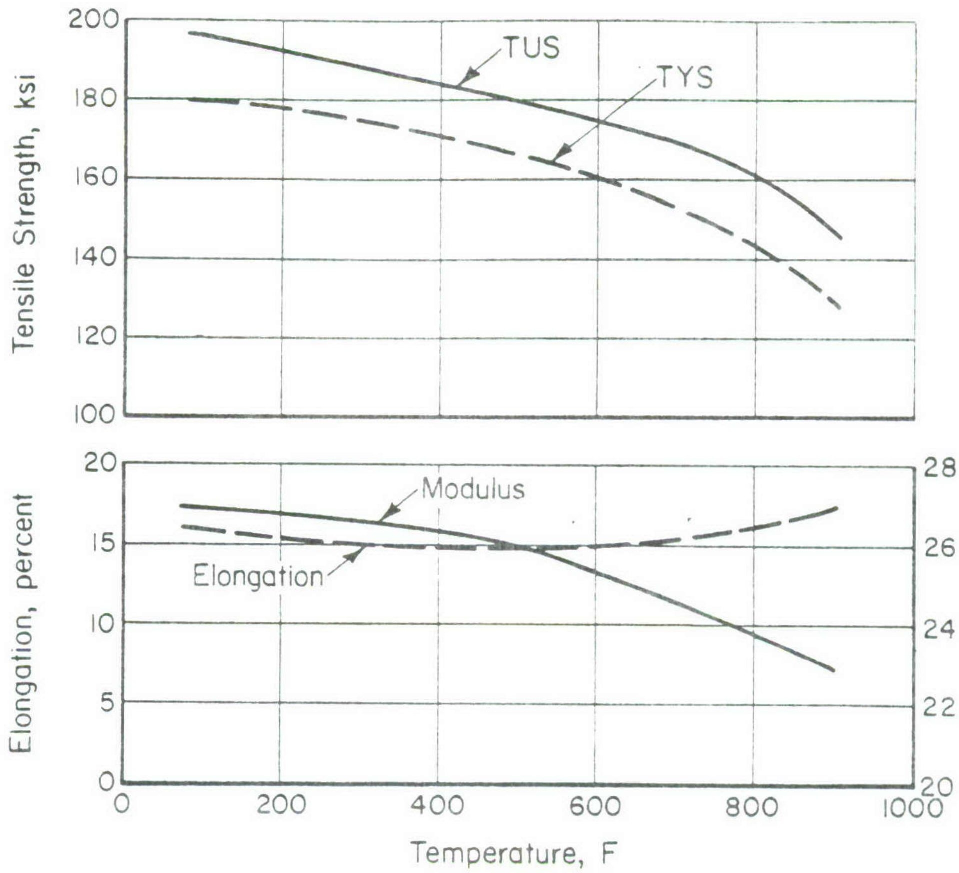


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HP 9Ni-4Co-0.20C FORGED BAR

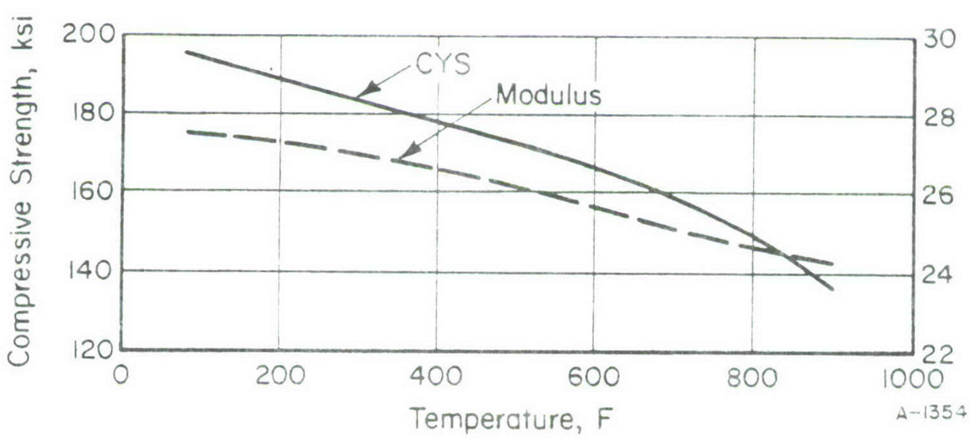


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF HP 9Ni-4Co-0.20C FORGED BAR

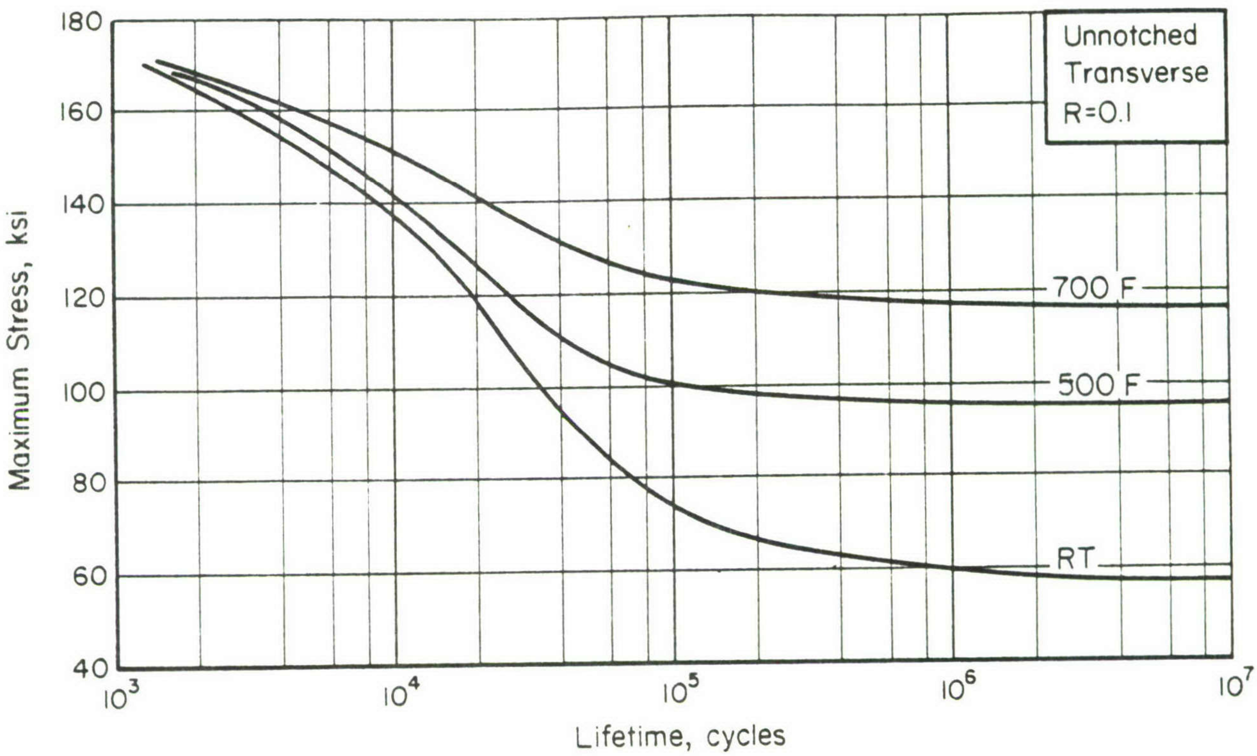


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED HP 9Ni-4Co-0.20C FORGED BAR

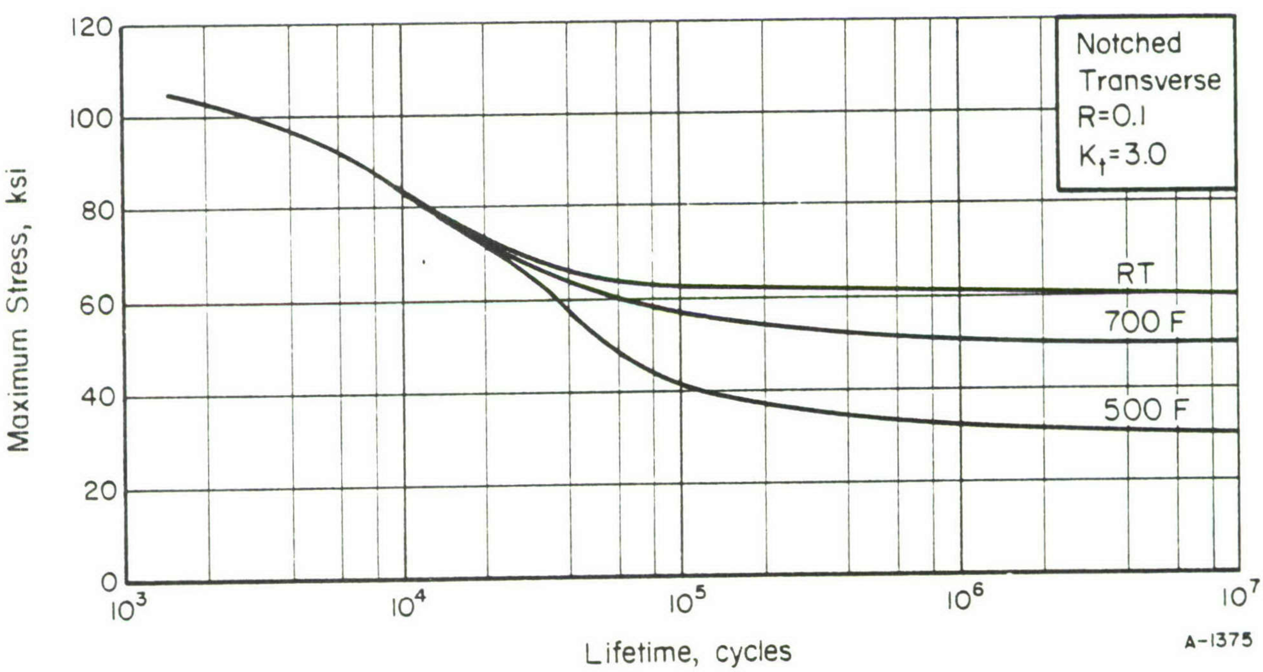


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) HP 9Ni-4Co-0.20C FORGED BAR

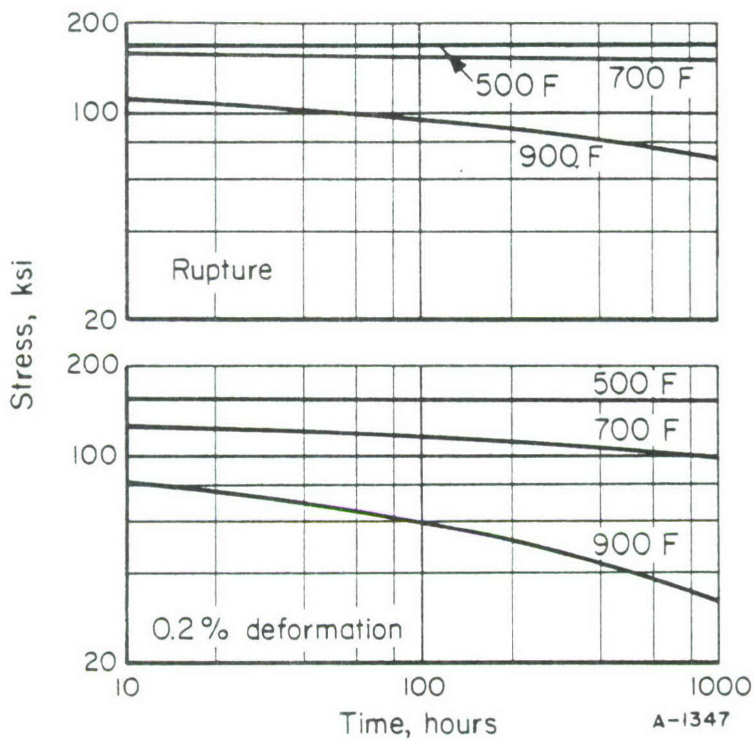


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR HP 9Ni-4Co-0.20C FORGED BAR (TRANSVERSE)

PH 13-8 Mo Stainless Steel

Material Description

This alloy is a martensitic precipitation hardenable stainless steel developed by the Armco Steel Corporation. It can be heat treated to high strength levels and exhibits good ductility in the transverse direction. This transverse direction toughness is obtained by composition balance designed to prevent formation of delta ferrite in the structure, low carbon content to minimize grain boundary carbide precipitation, and double vacuum melting to reduce alloy segregation. The alloy reportedly has excellent resistance to stress corrosion cracking in synthetic seawater and excellent resistance to corrosion in a 5 percent salt spray environment.

The material used in this evaluation was obtained as a 4-inch x 5-inch x 5 foot forged bar from Armco Heat 1W0241. The composition was as follows:

Chemical Composition	Percent
Carbon	0.035
Manganese	0.01
Phosphorus	0.002
Sulfur	0.003
Silicon	0.02
Chromium	12.62
Nickel	8.24
Molybdenum	2.16
Aluminum	1.02
Iron	Balance

Processing and Heat Treating

Specimens were machined in the as-received Contition A and then heat treated at 1000 F for 4 hours to Condition H 1000.

PH 13-8 Mo Stainless Steel Data[a]

Condition: H1000
Thickness: 4-inch x 6-inch forged bar

Properties	Temperature, F				
	RT	400	500	700	900
Tension					
TUS (longitudinal), ksi	192.7	U	169.0	157.7	128.3
TUS (transverse), ksi	190.3	U	168.3	157.3	127.0
TYS (longitudinal), ksi	187.3	U	164.7	151.3	119.0
TYS (transverse), ksi	183.3	U	163.7	149.7	118.0
e (longitudinal), percent in 2 in.	13.3	U	12.5	12.7	21.2
e (transverse), percent in 2 in.	13.8	U	11.5	12.5	21.5
RA (longitudinal), percent	51.8	U	56.7	53.2	70.5
RA (transverse), percent	54.2	U	51.8	52.3	70.5
E (longitudinal), 10^6 psi	27.7	U	27.1	25.1	21.9
E (transverse), 10^6 psi	28.0	U	25.3	25.1	21.4
Compression					
CYS (longitudinal), ksi	187.7	U	158.3	150.7	118.3
CYS (transverse), ksi	199.7	U	169.7	158.7	121.3
E_c (longitudinal), 10^6 psi	30.0	U	26.2	25.8	23.2
E_c (transverse), 10^6 psi	30.0	U	25.7	24.4	23.0
Shear[b]					
SUS (longitudinal), ksi	121.3	U	U[c]	U	U
SUS (transverse), ksi	123.0	U	U	U	U
Impact[d]					
V-notch Charpy, ft. lb.					
(longitudinal)	34.0	U	U	U	U
(transverse)	27.7	U	U	U	U
Fracture Toughness					
K_{Ic} (longitudinal), ksi $\sqrt{in.}$	(e)	U	U	U	U
K_{Ic} (transverse), ksi $\sqrt{in.}$	(e)	U	U	U	U
Axial Fatigue (transverse)[f]					
Unnotched, R = 0.1					
10^3 cycles, ksi	215	200	U	163	U
10^5 cycles, ksi	187	170	U	153	U
10^7 cycles, ksi	155	162	U	148	U
Notched, K_t = 3.0, R = 0.1					
10^3 cycles, ksi	183	147	U	121	U
10^5 cycles, ksi	70	80	U	74	U
10^7 cycles, ksi	50	70	U	66	U

Properties	Temperature, F				
	RT	400	500	700	900
Creep (transverse)					
0.2% plastic deformation, 100 hr, ksi	NA	U	150	106	37
0.2% plastic deformation, 1000 hr, ksi	NA	U	140	95	28
Stress Rupture (transverse)					
Rupture, 100 hr, ksi	NA	U	161	130	75
Rupture, 1000 hr, ksi	NA	U	160	125	60
Stress Corrosion(g)					
80% TYS, 1000 hr maximum	no cracks				
Coefficient of Thermal Expansion					
6.6×10^{-6} in./in./F (80 to 900 F)					
Density					
0.279 lb./in.^{3}					

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 3 specimens.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Six longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 191.0 ksi $\sqrt{\text{in.}}$ Since the size ratio, $2.5\ (K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, this K_Q value is not a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

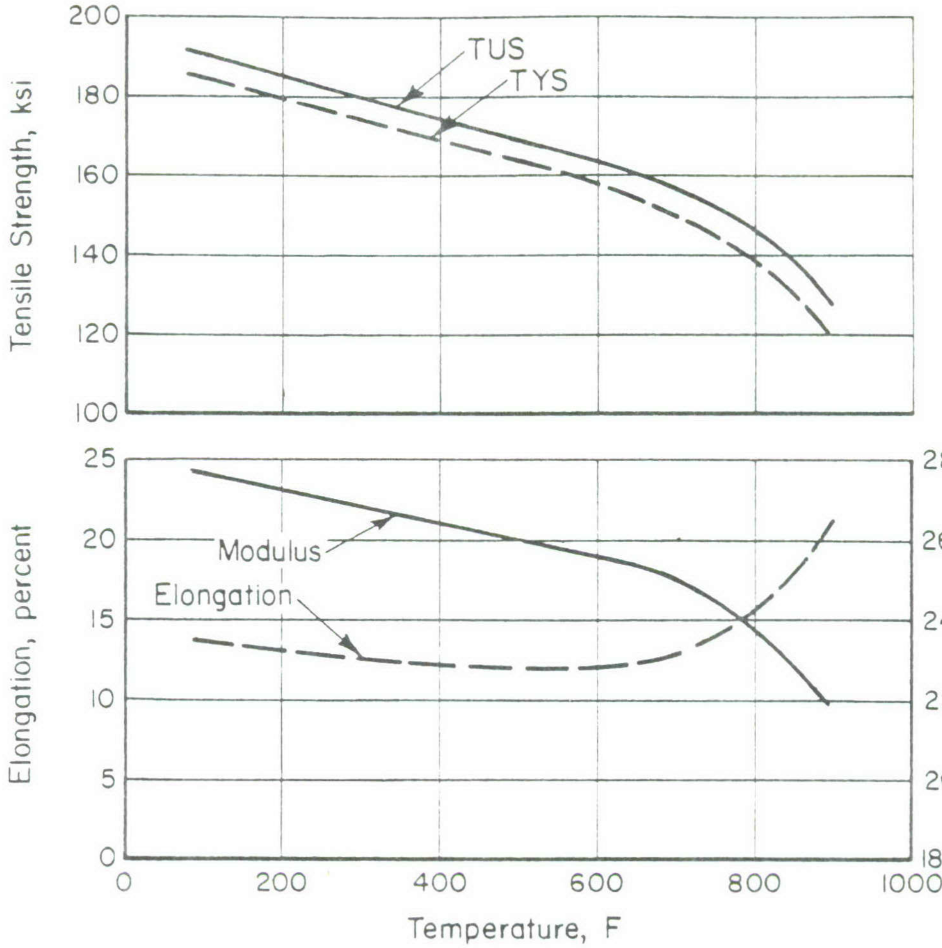


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF PH 13-8 Mo (H1000) FORGED BAR

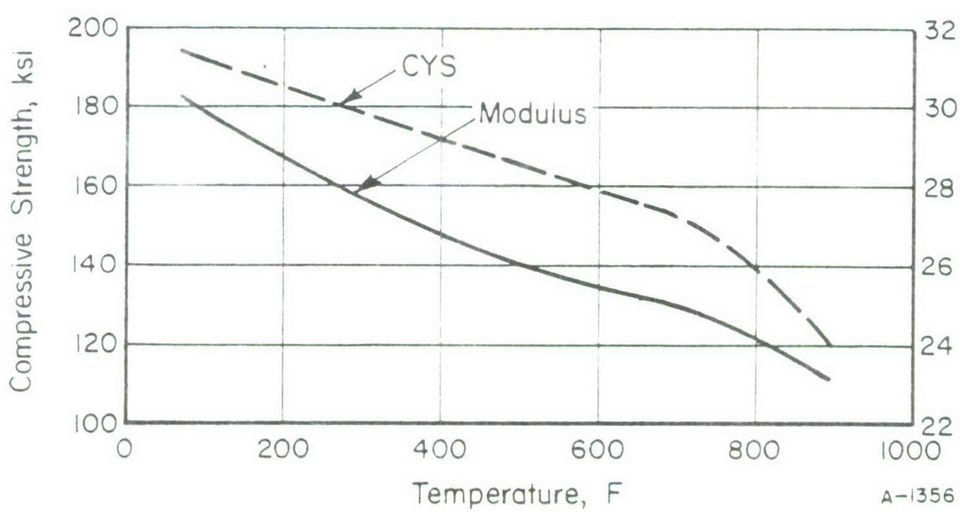


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF PH 13-8 Mo (H1000) FORGED BAR

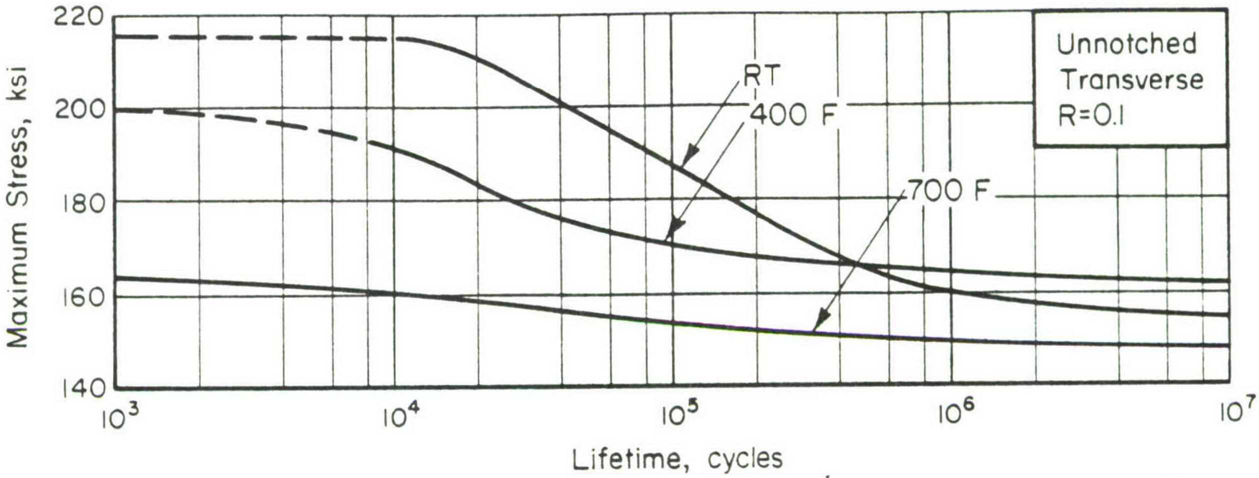


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED PH 13-8 Mo (H1000) FORGED BAR

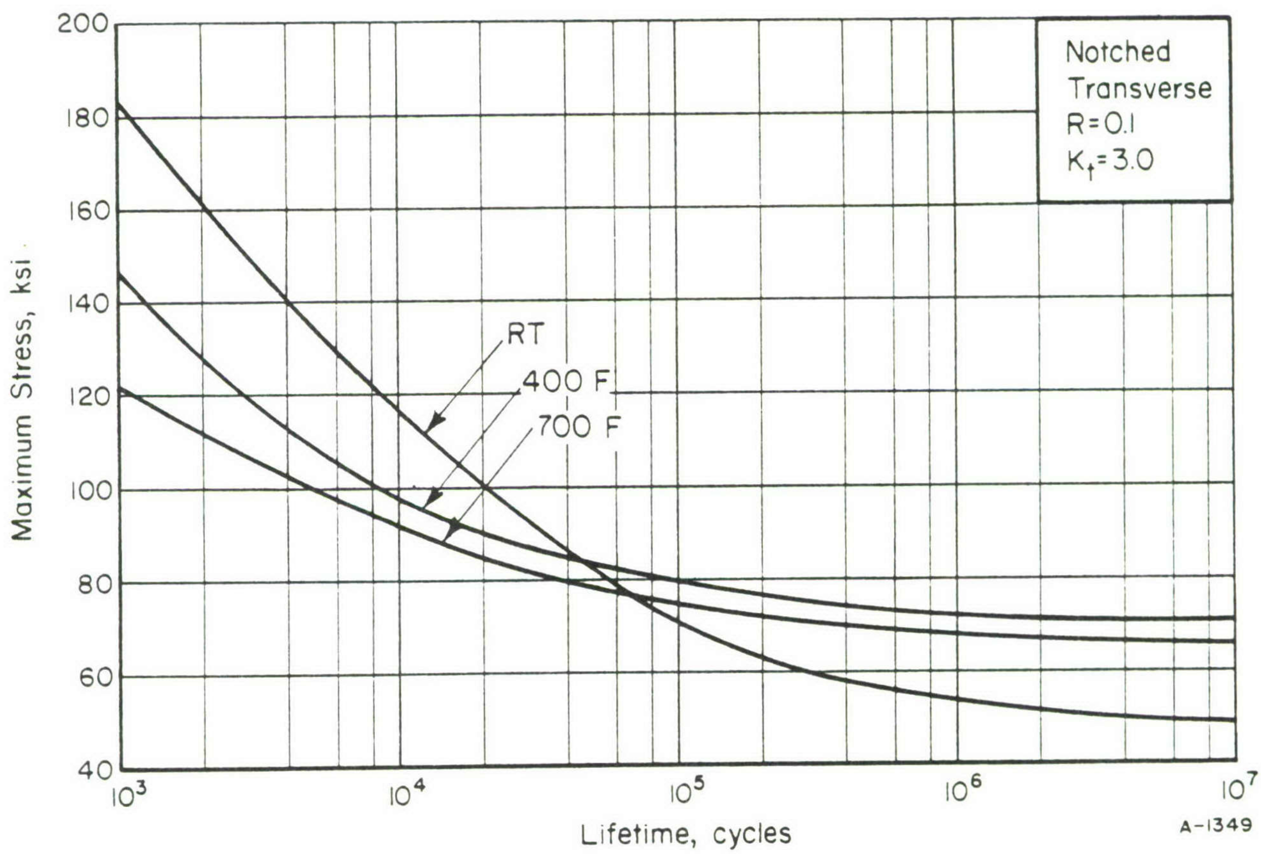


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) PH 13-8 Mo (H1000) FORGED BAR

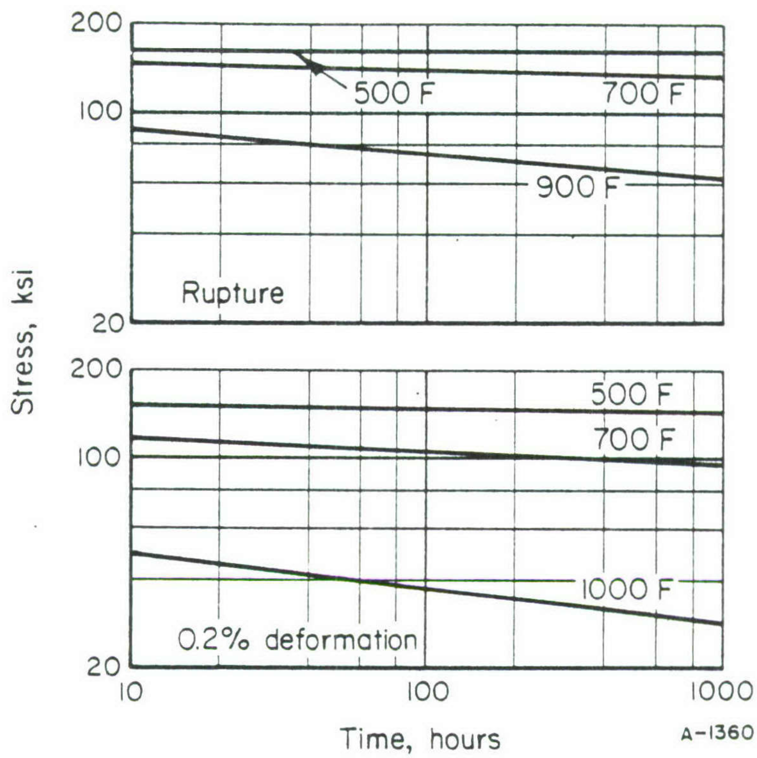


FIGURE 5. STRESS-RUPTURE AND CREEP DEFORMATION CURVES FOR PH 13-8 Mo (H1000) FORGED BAR (LONGITUDINAL)

7049-T76 Aluminum Extrusions

Material Description

Alloy 7049 was developed by Kaiser Aluminum and Chemical Corporation to have a strength level in the range of 7075-T6 and 7079-T6 coupled with a high resistance to stress corrosion cracking. Initial development and production was in the form of forgings and hand forgings. Further development has been in plates and extrusions.

The material evaluated was a 4-inch x 4-inch extrusion supplied by Kaiser with the following composition:

Chemical Composition	Percent
Zinc	7.6
Magnesium	2.5
Copper	1.5
Chromium	0.15
Silicon	0.25 max
Iron	0.35 max
Titanium	0.10 max
Manganese	0.20 max
Aluminum	Balance

Processing and Heat Treating

Specimens were tested in the as-received -T76 temper.

7049-T76 Aluminum Alloy Data[a]

Thickness: 4-inch x 4-inch extrusion

Properties	Temperature, F RT	250	350	500
Tension				
TUS (longitudinal), ksi	83.4	64.4	48.4	17.8
TUS (transverse), ksi	76.2	58.9	44.9	16.4
TUS (short transverse), ksi	76.3	U[c]	U	U
TYS (longitudinal), ksi	75.9	63.2	48.1	17.6
TYS (transverse), ksi	67.4	56.4	43.8	16.1
TYS (short transverse), ksi	67.7	U	U	U
e (longitudinal), percent in 2 in.	12.7	22.2	26.3	38.0
e (transverse), percent in 2 in.	11.2	16.8	19.5	32.3
e (short transverse), percent in 2 in.	11.7	U	U	U
RA (longitudinal), percent	35.6	53.1	71.0	93.0
RA (transverse), percent	23.3	34.4	51.3	87.3
RA (short transverse), percent	22.6	U	U	U
E (longitudinal), 10^6 psi	10.7	9.3	8.2	7.6
E (transverse), 10^6 psi	9.9	9.3	8.4	7.3
E (short transverse), 10^6 psi	10.4	U	U	U
Compression				
CYS (longitudinal), ksi	78.8	69.8	52.7	19.0
CYS (transverse), ksi	74.7	63.3	48.8	17.7
E_c (longitudinal), 10^6 psi	10.9	9.9	9.0	6.5
E_c (transverse), 10^6 psi	10.5	10.2	9.1	7.7
Shear[b]				
SUS (longitudinal), ksi	45.4	U	U	U
SUS (transverse), ksi	42.8	U	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	5.8	U	U	U
(transverse)	1.6	U	U	U
Fracture Toughness				
K_{Ic} (longitudinal), ksi $\sqrt{in.}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	70	70	67	U
10^5 cycles, ksi	55	57	51	U
10^7 cycles, ksi	39	50	43	U

7049-T76 Aluminum Alloy Data (continued)

Properties	RT	Temperature, F 250	350	500
Axial Fatigue (transverse) (continued)				
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	48	45	45	U
10^5 cycles, ksi	19	17	17	U
10^7 cycles, ksi	11	7	7	U
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	36	13	2.4
0.2% plastic deformation, 1000 hr, ksi	NA	23	7	1.1
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	44	18	5
Rupture, 1000 hr, ksi	NA	39	12	3.5
Stress Corrosion[(g)]				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
12.9×10^{-6} in./in./F (80 to 212 F)				
Density				
0.099 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6L and 6T tests.

(e) Six longitudinal slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 54.1 ksi$\sqrt{\text{in.}}$ Since the size ratio, 2.5 $(K_Q/\text{TYS})^2$, was greater than both the specimen thickness and crack length in all tests, this K_Q value is not a valid K_{Ic} value by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

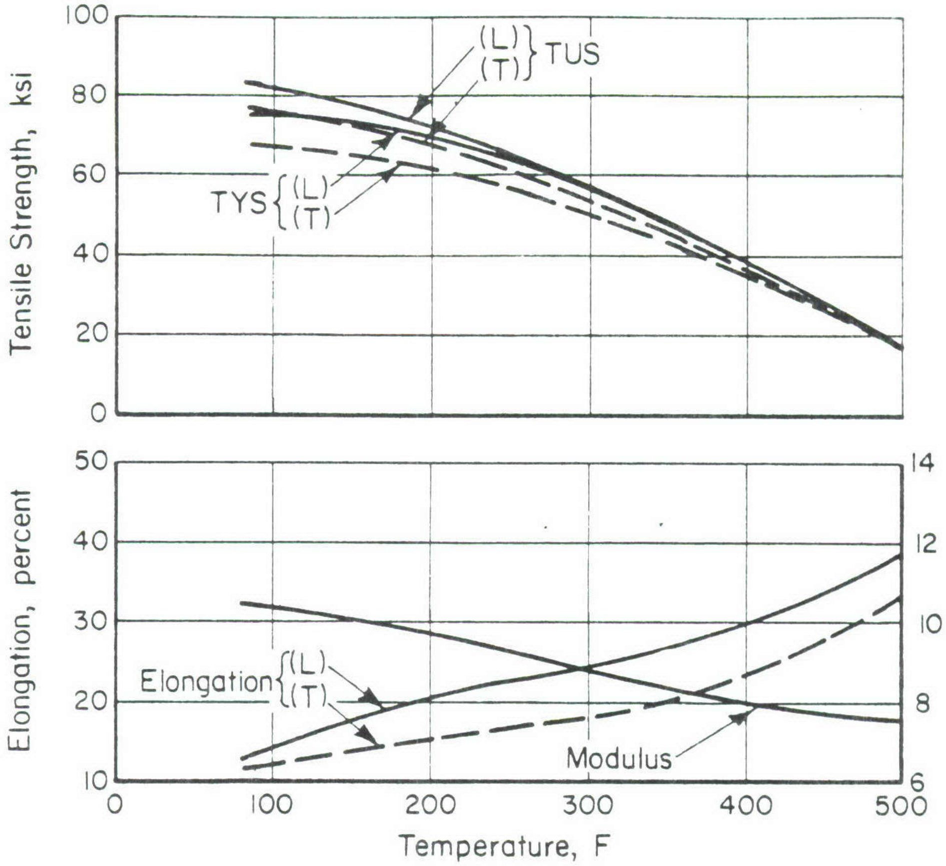


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T76 EXTRUSION

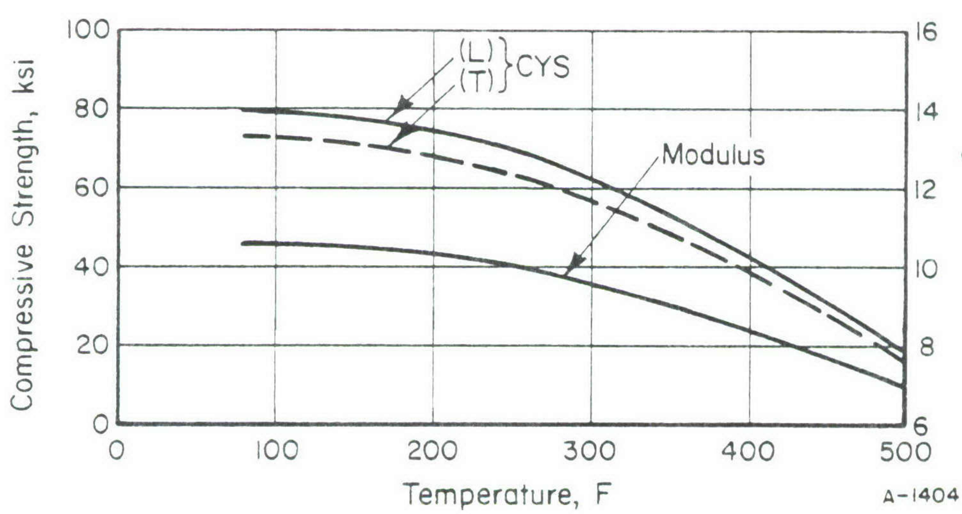


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7049-T76 EXTRUSION

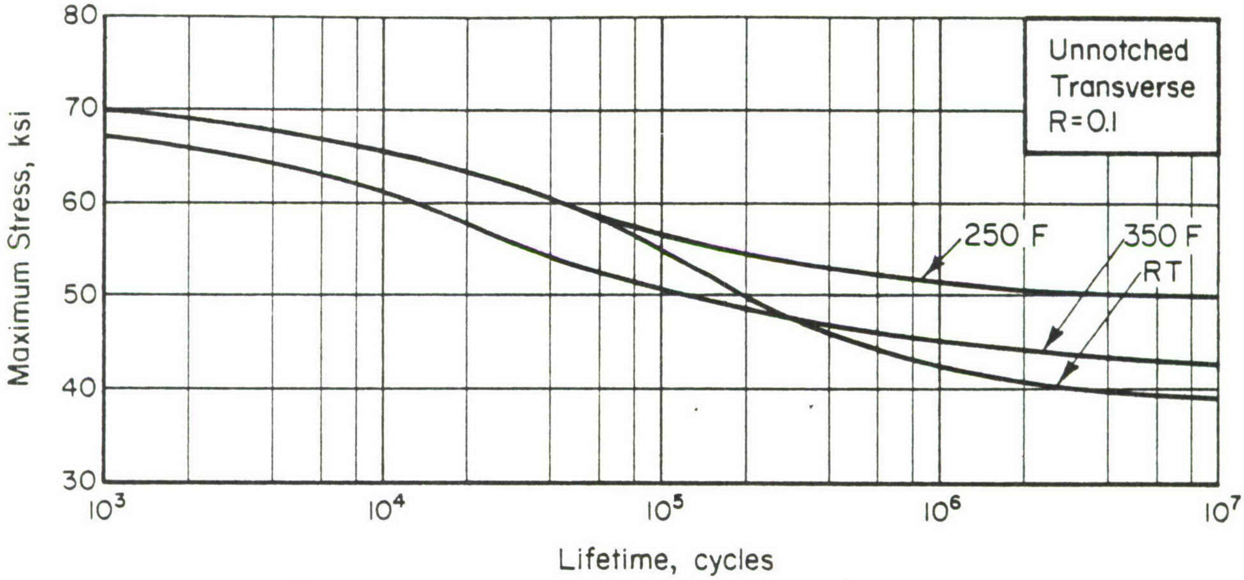


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED 7049-T76 EXTRUSIONS

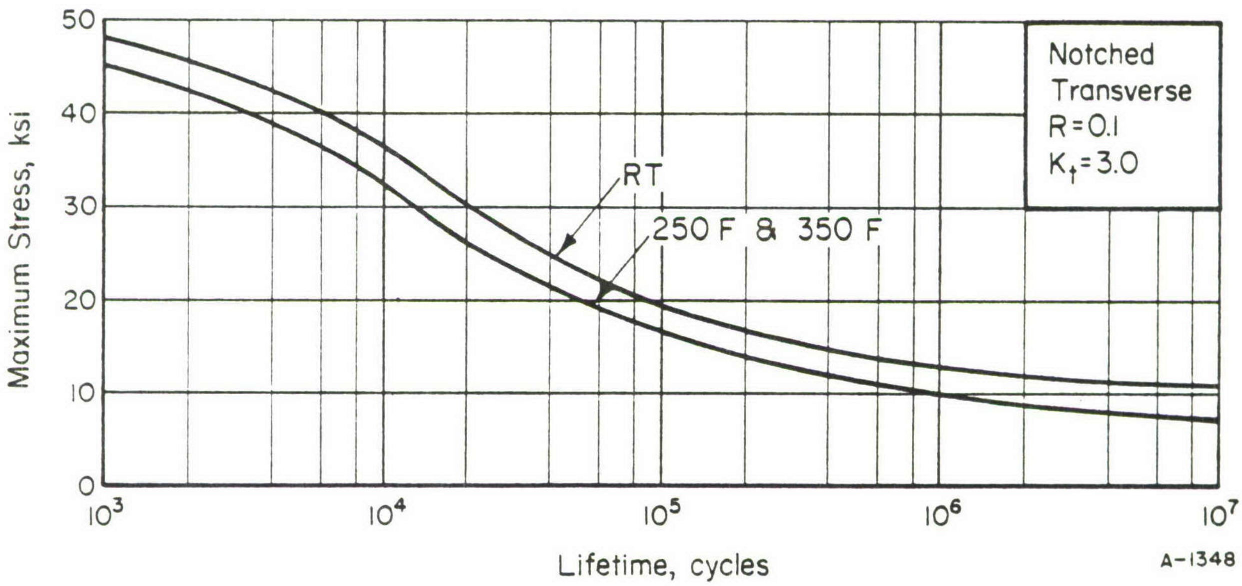


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 7049-T76 EXTRUSIONS

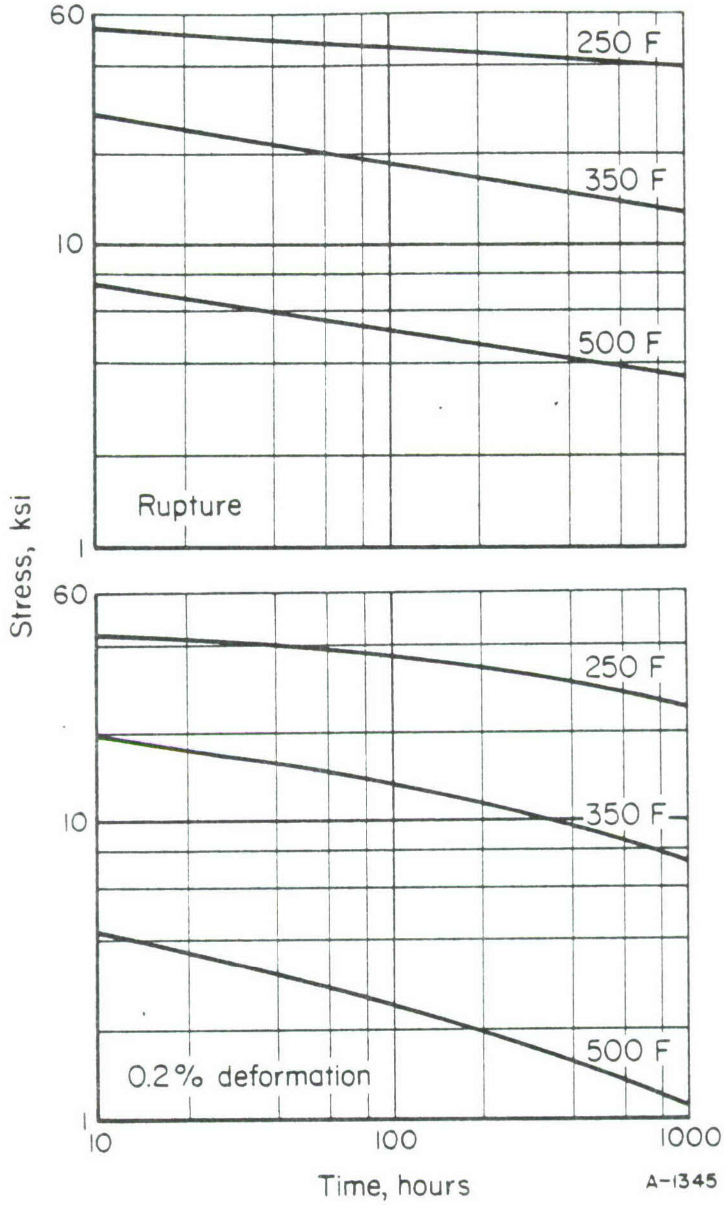


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7049-T76 EXTRUSIONS (TRANSVERSE)

Ti-6Al-2Sn-4Zr-6Mo Alloy

Material Description

Initially, this alloy was developed by the Titanium Metals Corporation as an off-shoot of the Ti-6Al-2Sn-4Zr-2Mo high temperature alloy. Studies had shown that increasing the molybdenum content beyond the 2 percent level resulted in an alloy having improved room and elevated temperature strength with good creep resistance. During early development, investigations were limited to the evaluation of the alloy as a heavy section forging alloy. Promising high temperature properties achieved in heat-treated sections up to 3 inches suggested the alloy might also be useful as a sheet alloy since it should be air hardenable at sheet gages.

The material used in this evaluation was 0.075 inch sheet obtained from TMCA. It had the following composition:

Chemical Composition	Percent
Aluminum	5.98
Tin	1.99
Zirconium	3.94
Molybdenum	5.86
Iron	0.057
Oxygen	0.10
Nitrogen	0.004
Titanium	Balance

Processing and Heat Treating

Specimens were machined in the as-received condition and heat-treated as follows:

(1) 1600 F, 15 minutes, air cooled,

(2) 1325 F, 15 minutes, air cooled,

(3) 1100 F, 2 hours, air cooled.

Ti-6Al-2Sn-4Zr-6Mo Data[a]

Condition: Solution treated and aged
Thickness: 0.080-inch sheet

Properties	Temperature, F RT	400	700	1000
Tension				
TUS (longitudinal), ksi	168.0	148.3	140.7	105.3
TUS (transverse), ksi	169.4	150.0	142.0	106.6
TYS (longitudinal), ksi	160.0	127.7	114.3	97.3
TYS (transverse), ksi	163.0	130.7	117.0	98.9
e (longitudinal), percent in 2 in.	12.3	14.8	14.5	36.3
e (transverse), percent in 2 in.	11.6	14.2	14.3	35.3
E (longitudinal), 10^6 psi	17.5	16.3	15.1	12.8
E (transverse), 10^6 psi	17.2	15.6	14.6	12.8
Compression				
CYS (longitudinal), ksi	167.3	133.3	123.3	110.7
CYS (transverse), ksi	170.6	138.0	126.7	112.7
E_c (longitudinal), 10^6 psi	19.4	17.9	16.3	13.9
E_c (transverse), 10^6 psi	18.9	17.6	16.1	13.6
Shear[b]				
SUS (longitudinal), ksi	96.8	U[c]	U	U
SUS (transverse), ksi	98.1	U	U	U
Fracture Toughness[d]				
K_c (crack direction LT), ksi $\sqrt{in.}$	132	U	U	U
Axial Fatigue (transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	140	140	130	U
10^5 cycles, ksi	108	108	103	U
10^7 cycles, ksi	100	100	100	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	78	85	85	U
10^5 cycles, ksi	35	39	35	U
10^7 cycles, ksi	30	35	25	U

Ti-6Al-2Sn-4Zr-6Mo Data (continued)

Properties	RT	Temperature 700	900	1100
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	113	29	1.9
0.2% plastic deformation, 1000 hr, ksi	NA	90	14	1.1
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	142	101	19
Rupture, 1000 hr, ksi	NA	140	90	7.5
Stress Corrosion(f)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
5.5×10^{-6} in./in./F (80 to 1000 F)				
Density				
0.165 lb./in.^{3}				

(a) Values given are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Values for fatigue, creep, and stress-rupture are from curves generated using a greater number of tests.

(b) Single-shear sheet-type specimen; average of 3 tests.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 inches x 36 inches with EDM flaw in center.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

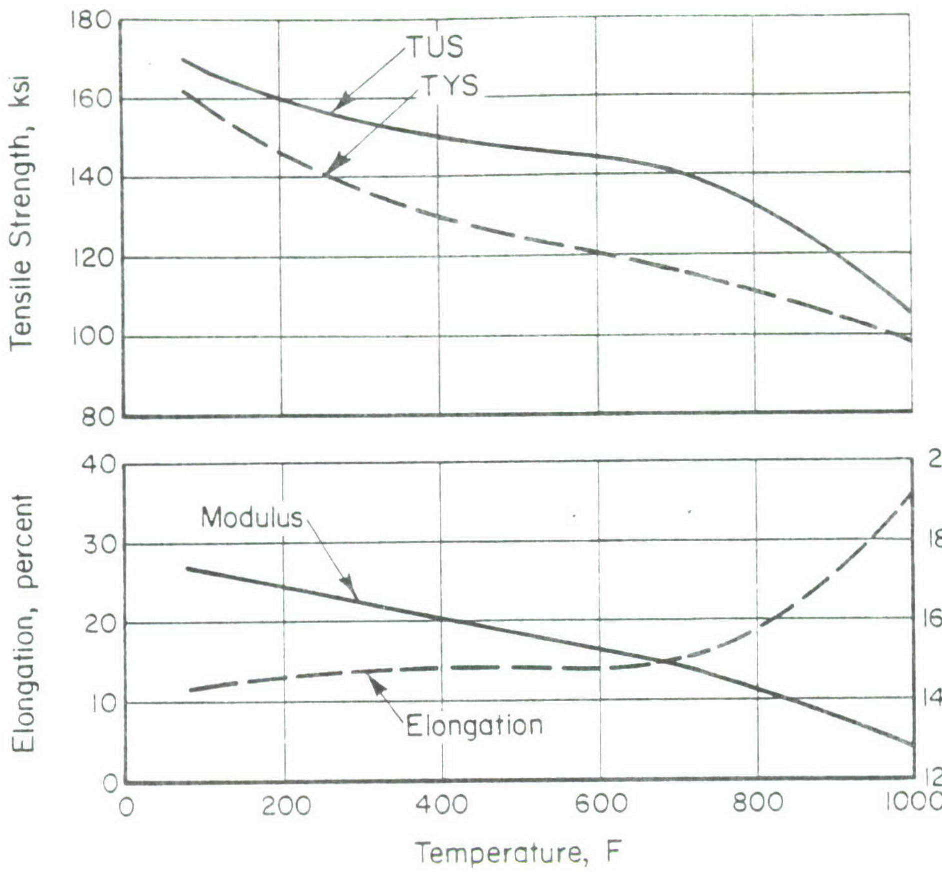


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-2Sn-4Zr-6Mo SHEET

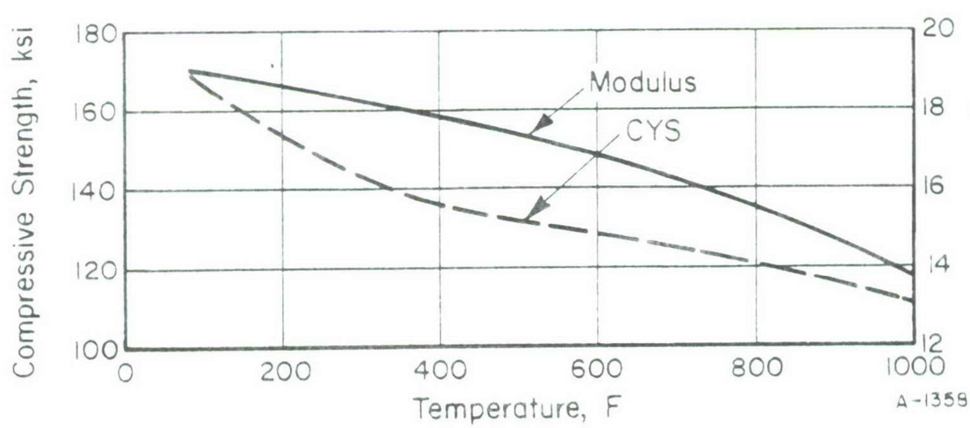


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-2Sn-4Zr-6Mo SHEET

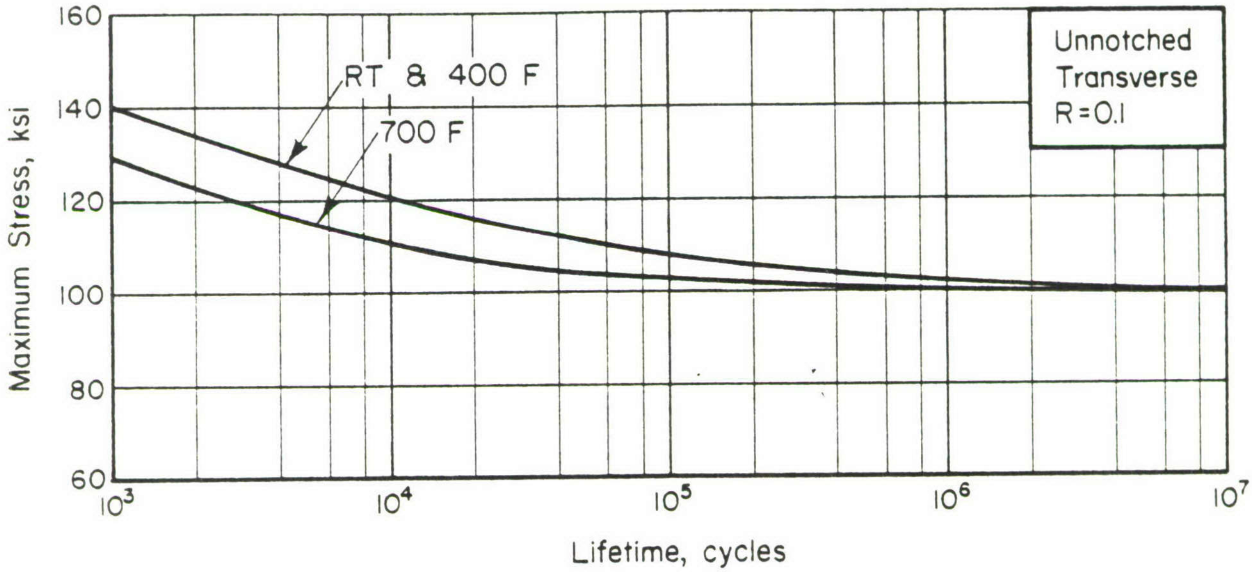


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED Ti-6Al-2Sn-4Zr-6Mo SHEET

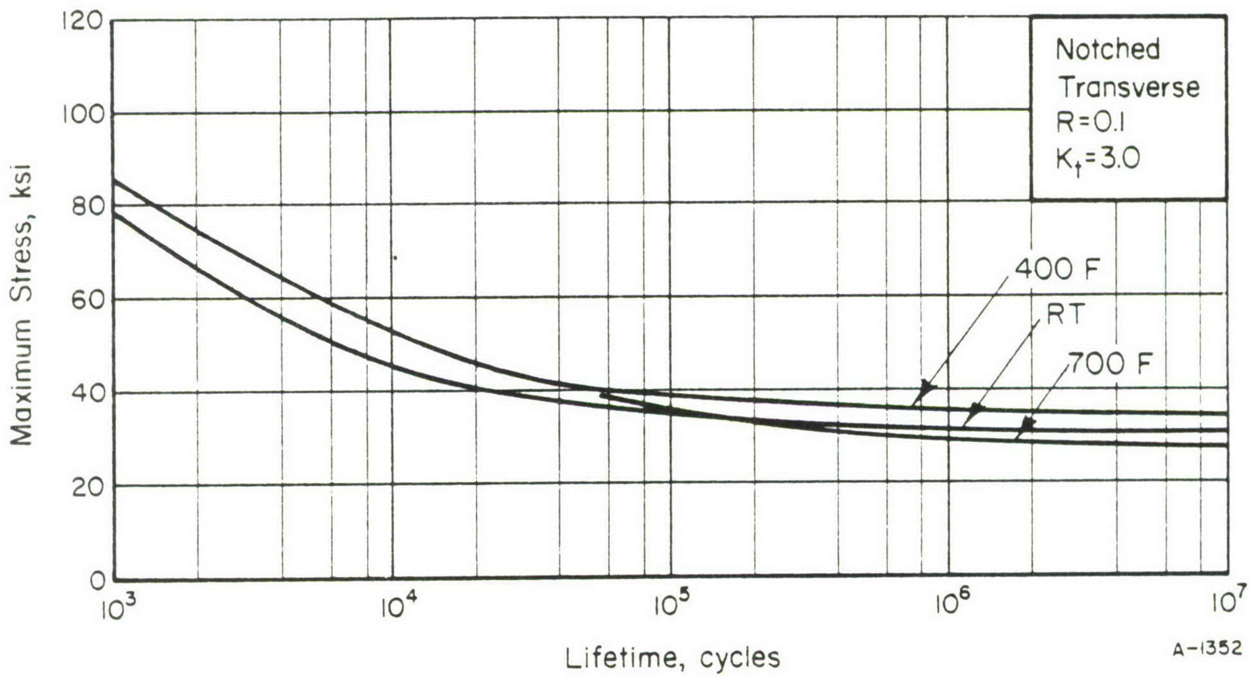


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) Ti-6Al-2Sn-4Zr-6Mo SHEET

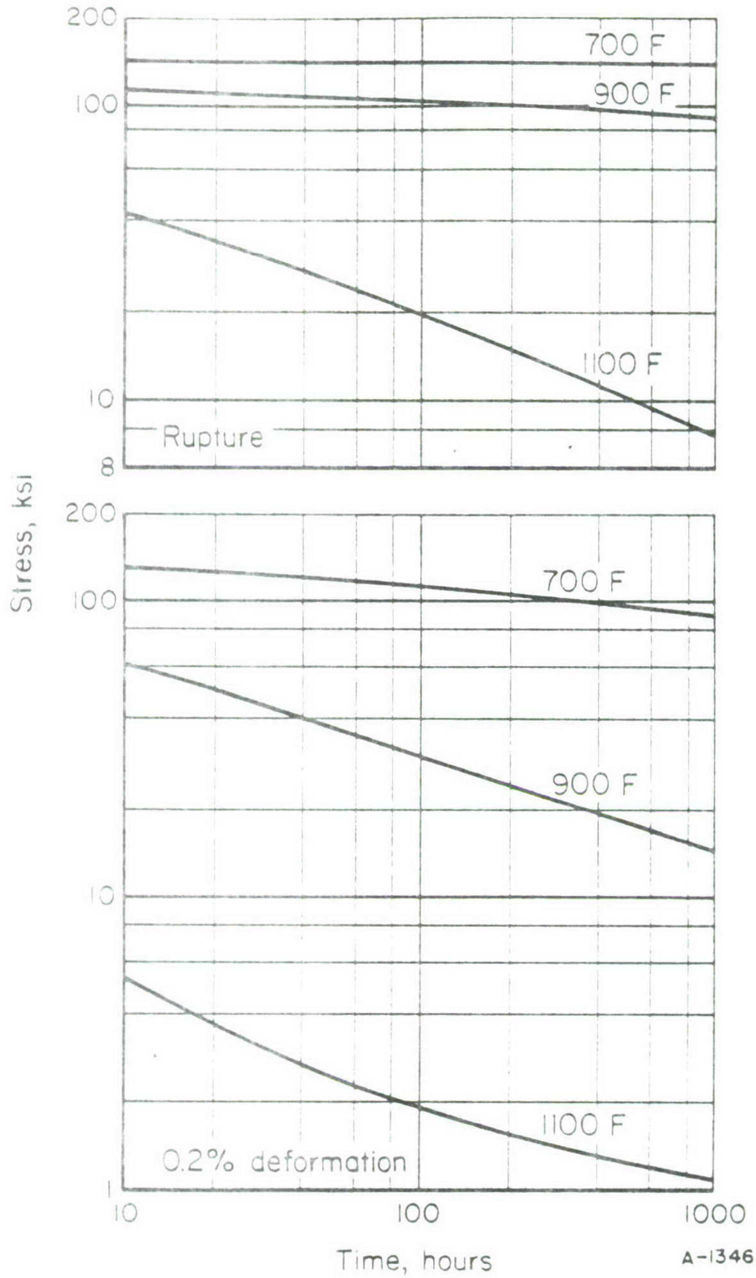


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Sn-4Zr-6Mo SHEET (TRANSVERSE)

Inconel 702 Alloy

Material Description

Inconel alloy 702 contains high aluminum content for excellent resistance to oxidation at temperatures up to 2400 F. At elevated temperatures, the surface of a nickel-rich, nickel-chromium alloy becomes covered with a compact layer of uniformly thick oxide; the aluminum content of alloy 702 improves the protective action of the oxide. Alloy 702 has good mechanical strength at high temperatures; age hardening improves the strength of the alloy up to about 1500 F.

The material used in this evaluation was 0.050 inch sheet from Huntington Alloy Products Division, Heat HT38C3DS. The composition was as follows:

Chemical Composition	Percent
Carbon	0.01
Manganese	0.02
Iron	0.32
Sulfur	0.007
Silicon	0.11
Copper	0.01
Chromium	16.34
Aluminum	3.12
Titanium	0.54
Nickel	79.50

Processing and Heat Treating

Specimens were machined in the as-received annealed condition and then aged at 1400 F for 5 hours.

Inconel 702 Alloy Data[(a)]

Condition: Aged
Thickness: 0.050-inch sheet

Properties	Temperature, F RT	600	1000	1400
Tension				
TUS (longitudinal), ksi	152.7	139.0	130.7	66.2
TUS (transverse), ksi	151.0	137.7	128.3	67.5
TYS (longitudinal), ksi	94.8	85.7	84.5	63.6
TYS (transverse), ksi	94.8	86.3	85.3	65.1
e (longitudinal), percent in 2 in.	34.8	35.8	36.3	9.3
e (transverse), percent in 2 in.	34.2	36.8	35.5	8.2
E (longitudinal), 10^6 psi	34.5	29.6	29.2	20.2
E (transverse), 10^6 psi	33.7	30.9	27.7	20.8
Compression				
CYS (longitudinal), ksi	99.4	91.0	90.2	68.0
CYS (transverse), ksi	101.0	93.6	91.0	70.5
E_c (longitudinal), 10^6 psi	34.4	35.0	30.2	21.0
E_c (transverse), 10^6 psi	34.7	33.3	30.6	20.7
Shear[(b)]				
SUS (longitudinal), ksi	116.2	U[(c)]	U	U
SUS (transverse), ksi	115.7	U	U	U
Fracture Toughness				
K_c, ksi $\sqrt{in.}$	(d)	U	U	U
Axial Fatigue (transverse)[(e)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	90	90	77	U
10^5 cycles, ksi	73	73	70	U
10^7 cycles, ksi	31	41	48	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	79	74	74	U
10^5 cycles, ksi	53	51	51	U
10^7 cycles, ksi	25	37	37	U

Inconel 702 Alloy Data (continued)

Properties	RT	800	1100	1400
	Temperature, F			
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	115	60	14
0.2% plastic deformation, 1000 hr, ksi	NA	95	40	4.5
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	122	75	22
Rupture, 1000 hr, ksi	NA	120	51	11
Stress Corrosion[(f)]				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
8.7×10^{-6} in./in./F (70 to 1500 F)				
Density				
0.305 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Single-shear sheet-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Specimens were full sheet thickness x 18 inches x 36 inches with EDM flaw in center. The net section yield stress at fracture was greater than the tensile yield strength of the material; therefore, the K values are considered not valid.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

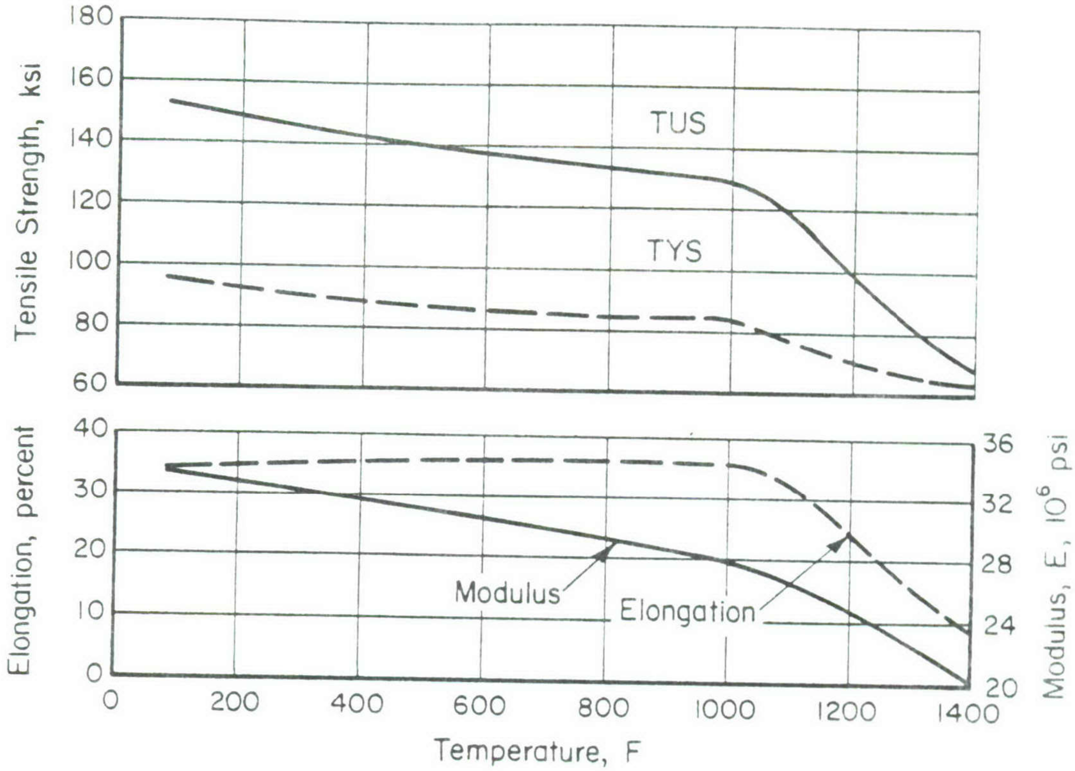


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF INCONEL 702 SHEET (AGED)

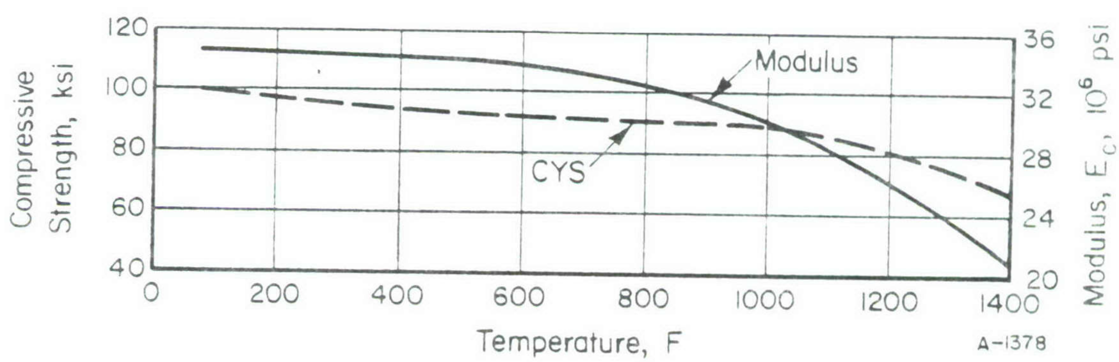


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF INCONEL 702 SHEET (AGED)

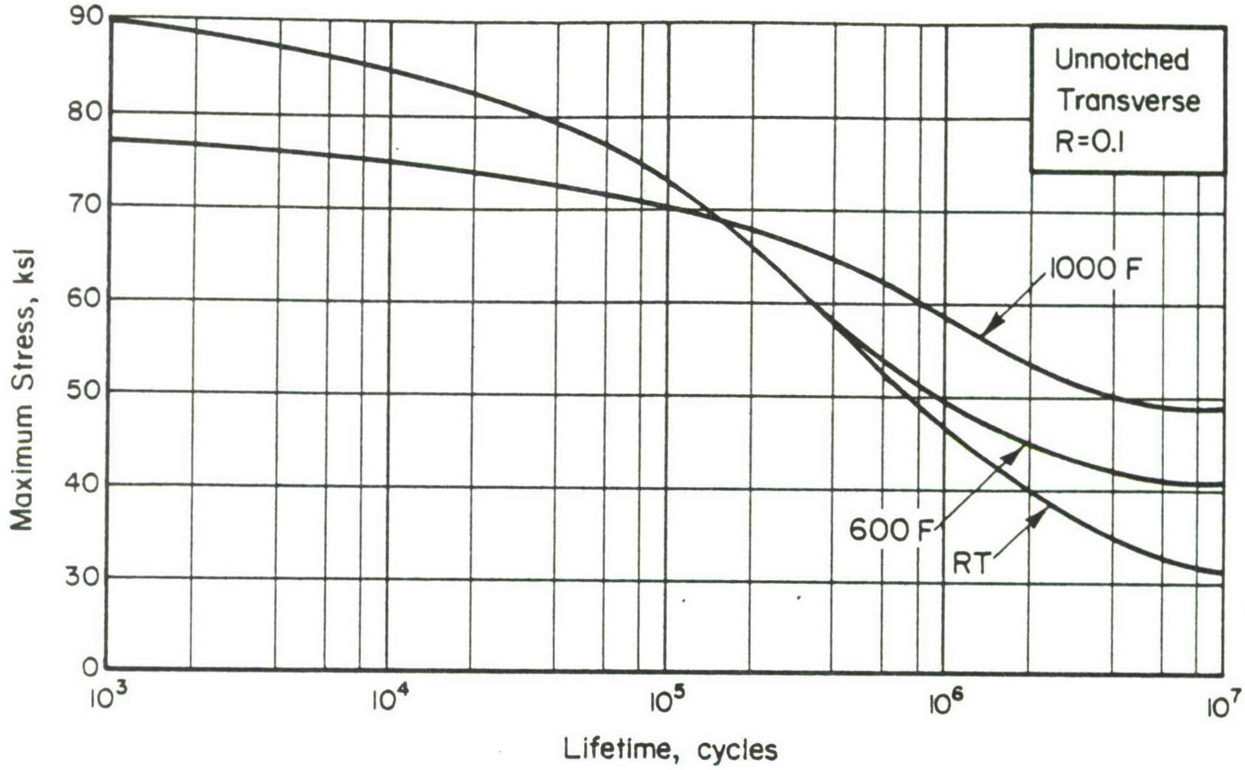


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED INCONEL SHEET (AGED)

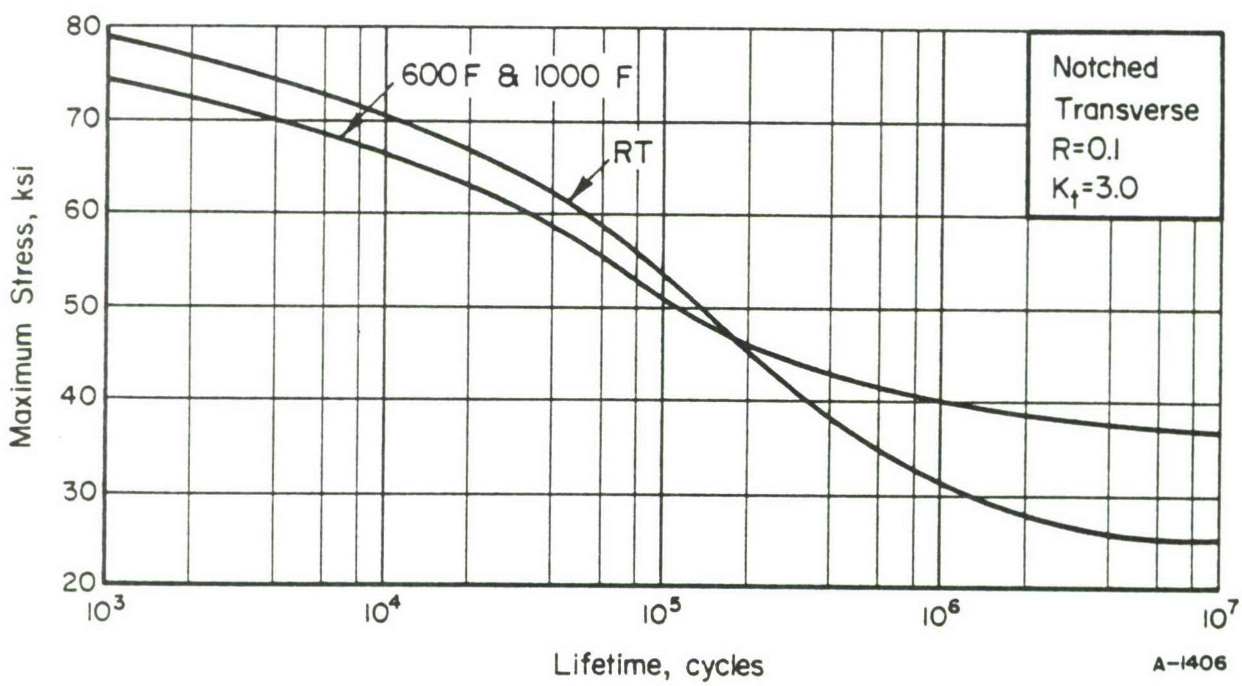


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) INCONEL 702 SHEET (AGED)

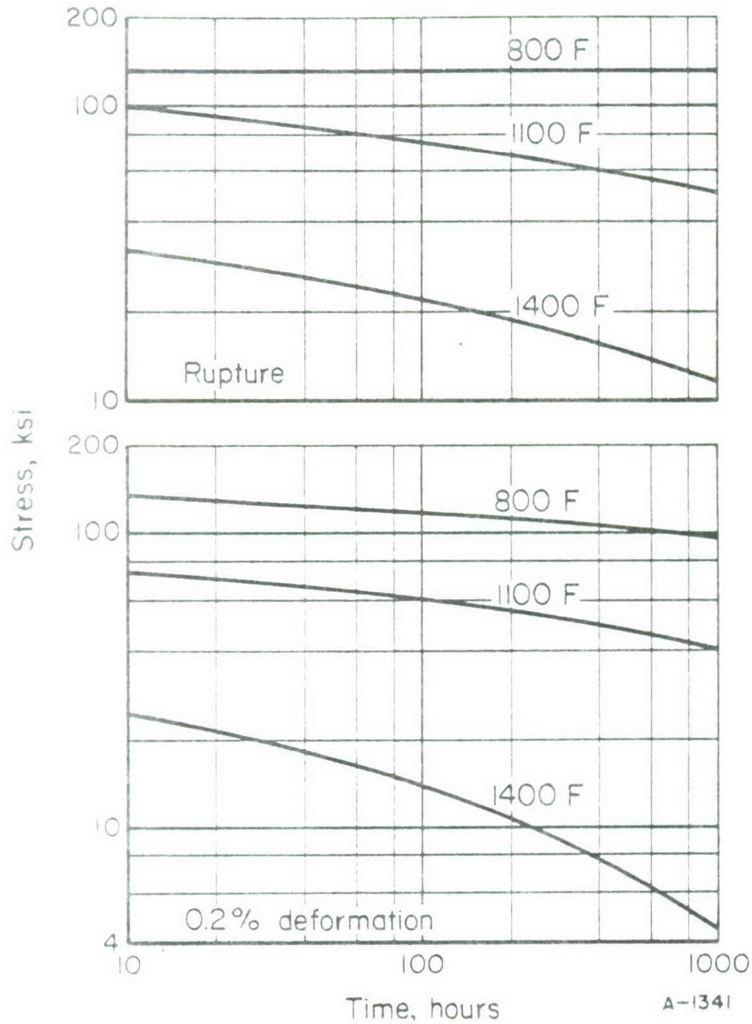


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR INCONEL 702 SHEET (AGED) (TRANSVERSE)

Inconel 706 Alloy

Material Description

Inconel alloy 706 is a precipitation-hardenable, nickel-iron-chromium alloy with characteristics similar to those of Inconel 718, except that 706 has improved machinability. It has high strength at temperatures ranging from cryogenic to 1300 F. It also has good resistance to oxidation and corrosion over a broad range of temperatures and environments.

Fabrication of the alloy is enhanced by its good formability and weldability. Alloy 706 has excellent resistance to postweld strain-age cracking.

The material used in this evaluation was obtained as a 6-inch-square forging from INCO, Heat HT50C3HK. The composition was as follows:

Chemical Composition	Percent
Carbon	0.03
Manganese	0.12
Iron	36.37
Sulfur	0.007
Silicon	0.13
Copper	0.02
Chromium	16.32
Aluminum	0.28
Titanium	1.62
Columbium plus Tantalum	2.96
Nickel	42.12

Processing and Heat Treating

The 6-inch-square material was press forged to a 2 inch x 6 inch forging to make specimen blanks easier to obtain. After machining, specimens were heat treated as follows:

(1) 1800 F, 2 hours, air cool,

(2) 1550 F, 3 hours, air cool,

(3) 1325 F, 8 hours, furnace cool to 1150 F, hold for 18 hours, air cool.

Inconel 706 Alloy Data[a]

Condition: Solution treated and aged for optimum stress rupture strength

Thickness: 2-inch x 6-inch forged bar

Properties	RT	600	800	1000	1200
	Temperature, F				
Tension					
TUS (longitudinal), ksi	177.7	U	156.3	151.7	138.3
TUS (transverse), ksi	176.0	U	157.7	153.0	139.0
TYS (longitudinal), ksi	138.7	U	120.7	119.7	116.0
TYS (transverse), ksi	140.0	U	122.0	121.0	117.0
e (longitudinal), percent in 2 in.	22.2	U	21.7	21.0	25.5
e (transverse), percent in 2 in.	22.0	U	20.2	19.0	22.8
RA (longitudinal), percent	32.8	U	37.5	39.5	40.5
RA (transverse), percent	31.0	U	34.8	34.7	37.8
E (longitudinal), 10^6 psi	29.2	U	24.2	21.2	21.0
E (transverse), 10^6 psi	30.0	U	24.7	21.5	20.6
Compression					
CYS (longitudinal), ksi	149.7	U	126.7	123.3	120.0
CYS (transverse), ksi	149.0	U	129.3	124.7	121.3
E_c (longitudinal), 10^6 psi	31.1	U	24.3	23.0	22.5
E_c (transverse), 10^6 psi	31.4	U	24.2	24.0	22.2
Shear[b]					
SUS (longitudinal), ksi	117.2	U	U[c]	U	U
SUS (transverse), ksi	117.0	U	U	U	U
Impact[d]					
V-notch Charpy, ft. lb.					
(longitudinal)	31.8	U	U	U	U
(transverse)	26.4	U	U	U	U
Fracture Toughness					
K_{Ic} (longitudinal), ksi $\sqrt{\text{in.}}$	(e)	U	U	U	U
K_{Ic} (transverse), ksi $\sqrt{\text{in.}}$	(e)	U	U	U	U
Axial Fatigue (transverse)[f]					
Unnotched, R = 0.1					
10^3 cycles, ksi	156	144	U	132	U
10^5 cycles, ksi	121	96	U	90	U
10^7 cycles, ksi	60	60	U	53	U
Notched, K_t = 3.0, R = 0.1					
10^3 cycles, ksi	120	109	U	94	U
10^5 cycles, ksi	52	52	U	49	U
10^7 cycles, ksi	20	30	U	34	U

Properties	Temperature, F				
	RT	600	800	1000	1200
Creep (transverse)					
0.2% plastic deformation, 100 hr, ksi	NA	U	153	128	85
0.2% plastic deformation, 1000 hr, ksi	NA	U	152	121	76
Stress Rupture (transverse)					
Rupture, 100 hr, ksi	NA	U	154	141	100
Rupture, 1000 hr, ksi	NA	U	153	130	90
Stress Corrosion(g)					
80% TYS, 1000 hr maximum	no cracks				
Coefficient of Thermal Expansion					
9.8×10^{-6} in./in./F (70 to 1500 F)					
Density					
0.291 lb./in^3					

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Three longitudinal and three transverse slow-bend specimens were tested. Specimen size was 0.750-inch thick by 1.500 inches wide with a span of 6 inches. The average K_Q obtained was 87.1 ksi $\sqrt{in.}$ in the longitudinal direction and 87.9 ksi $\sqrt{in.}$ in the transverse direction. Since the size ratio, 2.5 $(K_Q/TYS)^2$, was greater than both the specimen thickness and crack length in all tests, these K_Q values are <u>not</u> valid K_{Ic} values by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

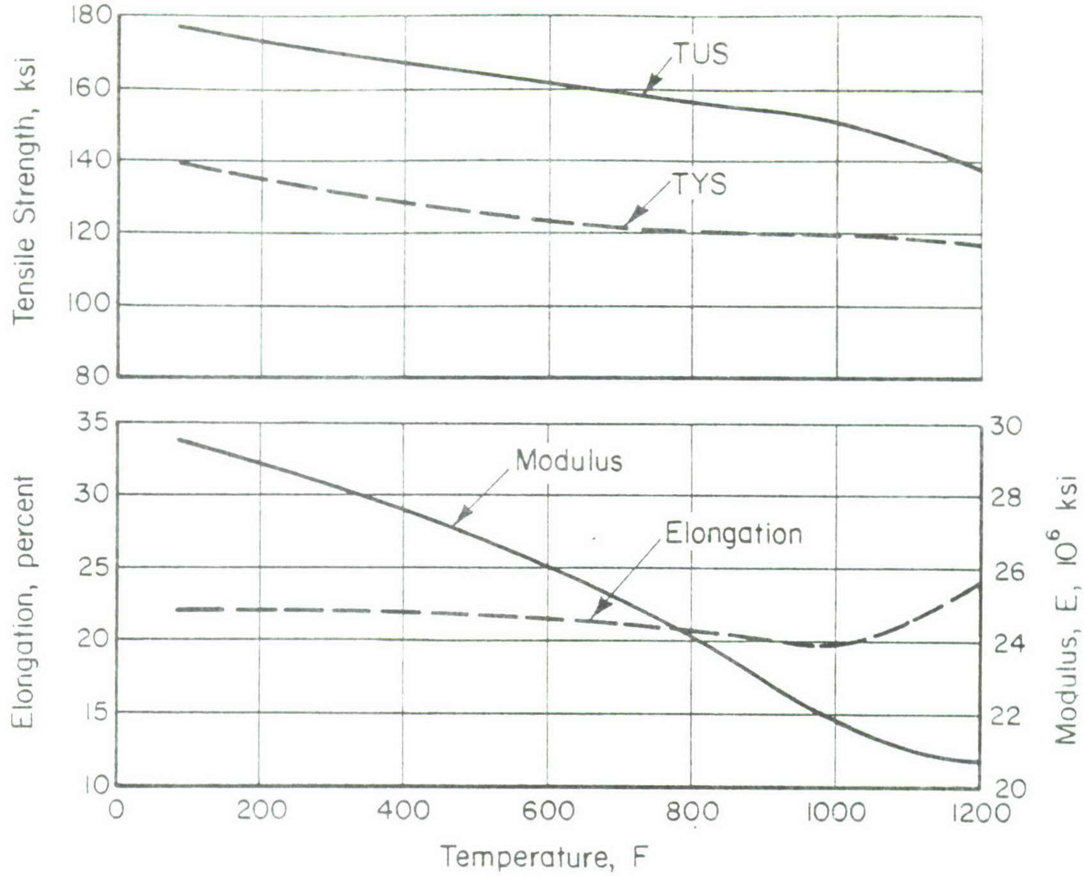


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

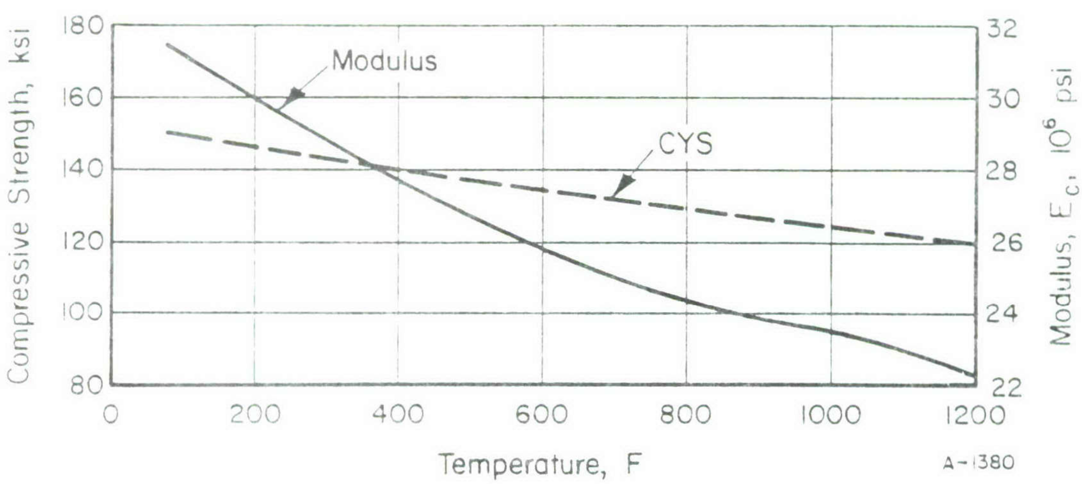


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

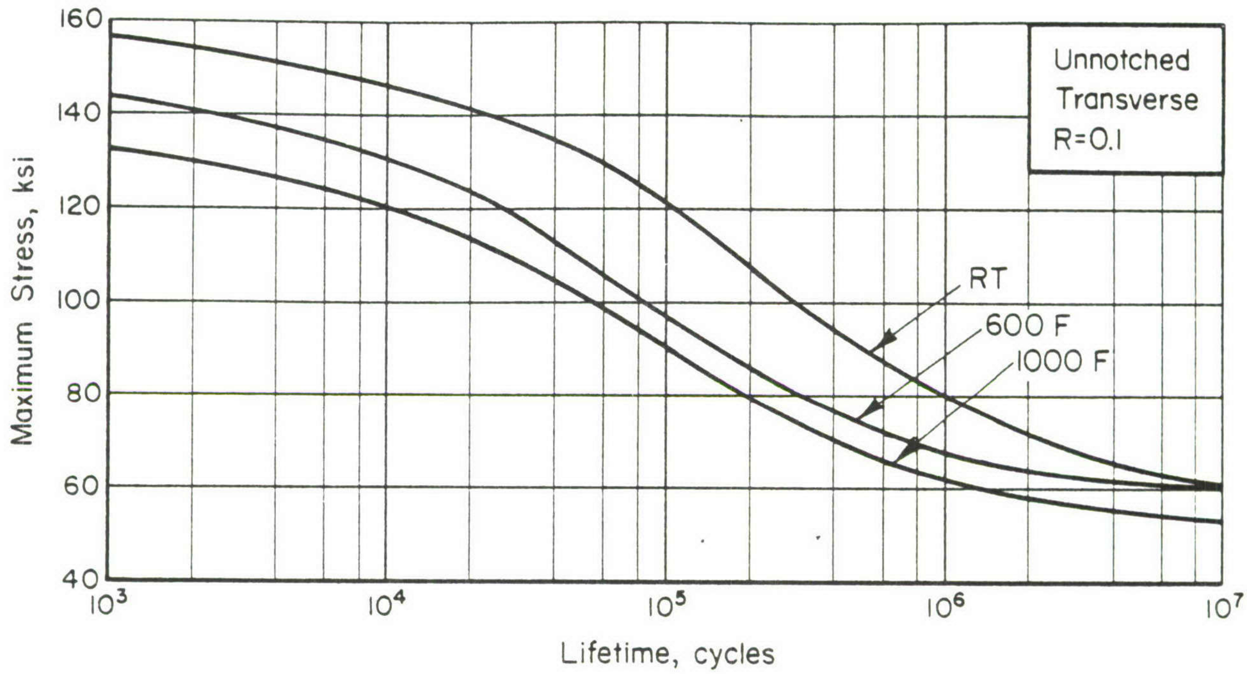


FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR UNNOTCHED INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

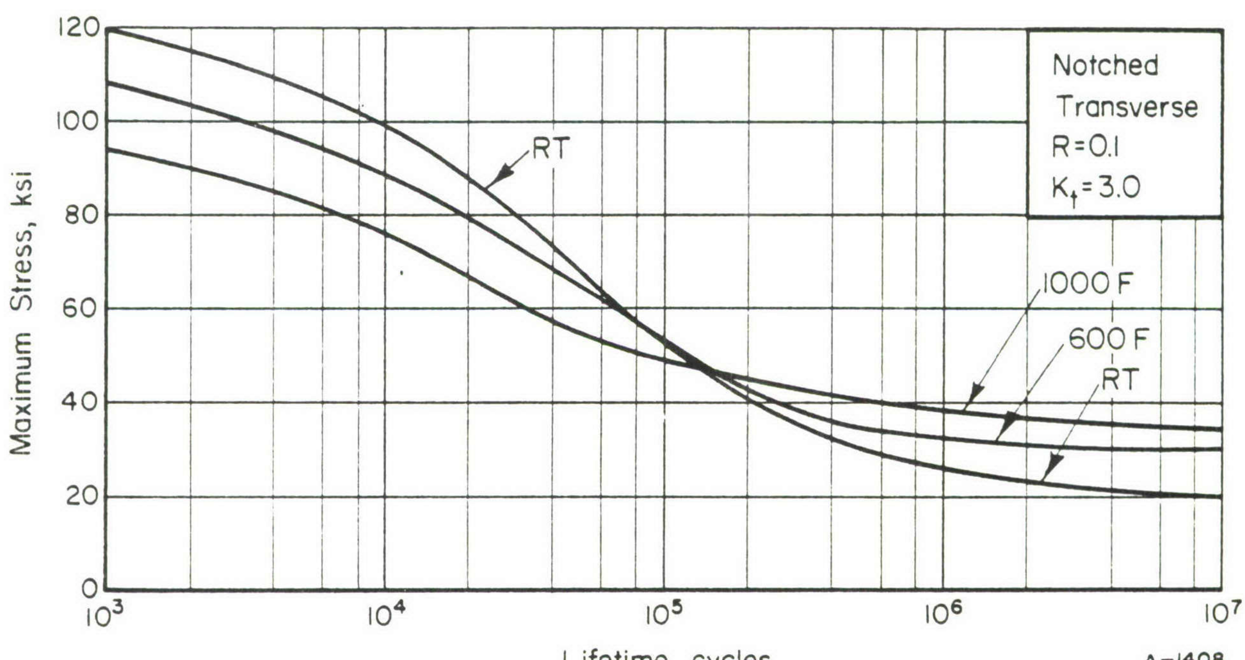


FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT)

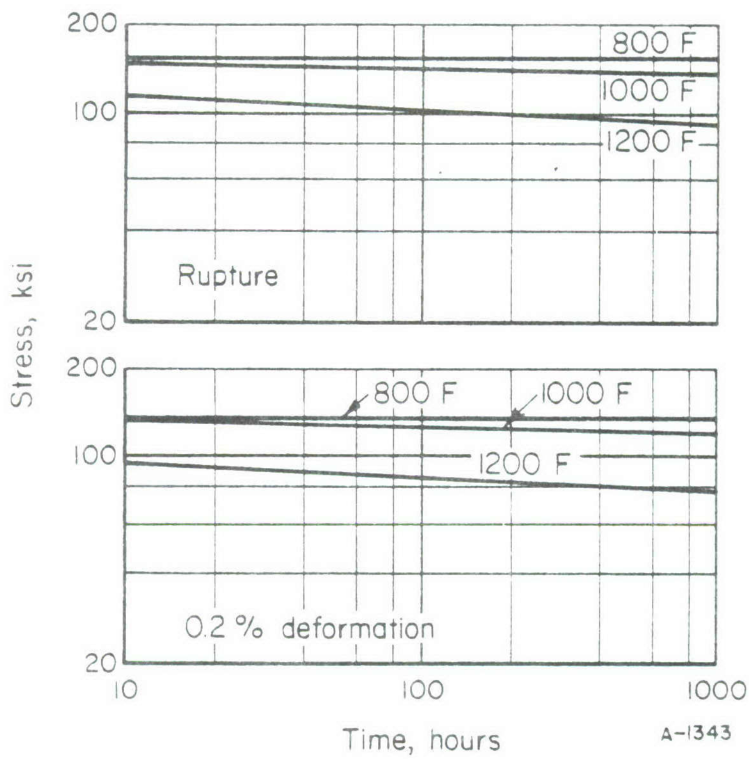


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR INCONEL 706 FORGED BAR (STRESS-RUPTURE HEAT TREATMENT) (TRANSVERSE)

X2048-T851 Aluminum Alloy

Material Description

Alloy X2048-T851 is a recent development of the Reynolds Metals Company. The development aim was a thick section alloy with high toughness and stability at moderate temperatures. The goal was to achieve the strength, fatigue resistance, corrosion resistance, and thermal stability of 2024-T851 or 2124-T851 and the toughness of 2219.

The material used for this evaluation was 3-inch plate produced within the following composition limits:

Copper	2.8 to 3.8
Manganese	0.20 to 0.60
Magnesium	1.2 to 1.8
Zinc	0.25 max
Titanium	0.10 max
Silicon	0.15 max
Iron	0.20 max
Others total	0.15 max
Aluminum	Balance .

Processing and Heat Treating

The specimens were tested in the as-received -T851 temper.

X2048-T851 Aluminum Alloy Data[a]

Thickness: 3-inch plate

Properties	Temperature, F			
	RT	250	350	500
Tension				
TUS (longitudinal), ksi	66.3	60.1	51.4	34.0
TUS (transverse), ksi	67.4	60.0	50.3	33.4
TUS (short transverse), ksi	67.1	U	U	U
TYS (longitudinal), ksi	60.4	56.8	49.1	31.7
TYS (transverse), ksi	60.9	56.3	48.8	31.6
TYS (short transverse), ksi	58.9	U	U	U
e (longitudinal), percent in 2 in.	8.3	12.7	14.2	9.5
e (transverse), percent in 2 in.	7.2	12.7	16.5	8.2
e (short transverse), percent in 2 in.	6.3	U	U	U
RA (longitudinal), percent	15.7	31.6	37.3	23.4
RA (transverse), percent	11.7	27.7	34.2	15.0
RA (short transverse), percent	9.4	U	U	U
E (longitudinal), 10^6 psi	10.2	9.9	9.3	8.3
E (transverse), 10^6 psi	10.5	9.8	9.3	7.7
E (short transverse), 10^6 psi	11.1	U	U	U
Compression				
CYS (longitudinal), ksi	60.9	56.7	50.6	35.2
CYS (transverse), ksi	60.6	56.0	51.1	32.9
E_c (longitudinal), 10^6 psi	11.3	10.2	9.6	9.4
E_c (transverse), 10^6 psi	11.1	10.3	9.7	9.6
Shear[b]				
SUS (longitudinal), ksi	39.3	U[c]	U	U
SUS (transverse), ksi	39.2	U	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	7.6	U	U	U
(transverse)	4.5	U	U	U
Fracture Toughness[e]				
K_{Ic}, crack direction LT, ksi $\sqrt{in.}$	32.0	U	U	U
K_{Ic}, crack direction TL, ksi $\sqrt{in.}$	29.1	U	U	U

X2048-T851 Aluminum Alloy
(continued)

Properties	RT	Temperature, F 250	350	500
Axial Fatigue (longitudinal)(f)				
Unnotched, R = 0.1				
10^3 cycles, ksi	68	68	68	U
10^5 cycles, ksi	38	37	35	U
10^7 cycles, ksi	32	28	25	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	54	54	50	U
10^5 cycles, ksi	22	21	19	U
10^7 cycles, ksi	16	14	12	U
Creep (longitudinal)				
0.2% plastic deformation, 100 hr, ksi	NA(c)	44	35	8.5
0.2% plastic deformation, 1000 hr, ksi	NA	41	19	4.5
Stress-Rupture (longitudinal)				
Rupture, 100 hr, ksi	NA	50	39	13
Rupture, 1000 hr, ksi	NA	47	32	8.5
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion	U			
Density				
.0994 lb/in^3				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Values are average of 6 tests in each direction.

(e) Values are average of 6 slow-bend type tests in each direction. Specimen size was 1.000-inch thick by 2.000 inches wide with a span of 8 inches. (Higher K_{Ic} values may be achieved with larger specimens. Reference J. G. Kaufman, "Notes for E-24.01 Meeting", held at Battelle's Columbus Laboratories on October 4, 1972.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

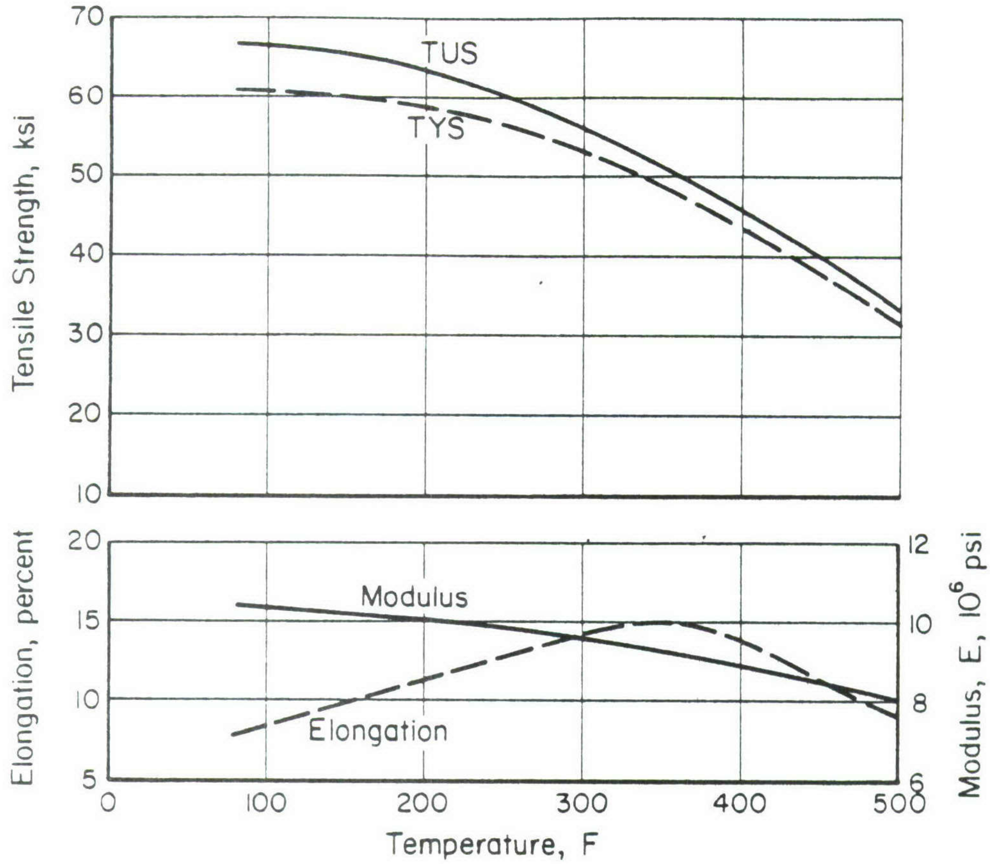


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF X2048-T851 PLATE

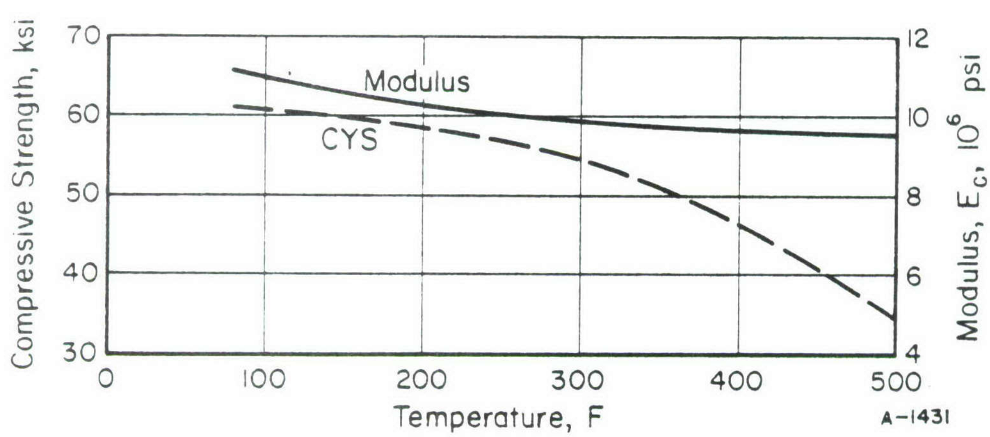


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF X2048-T851 PLATE

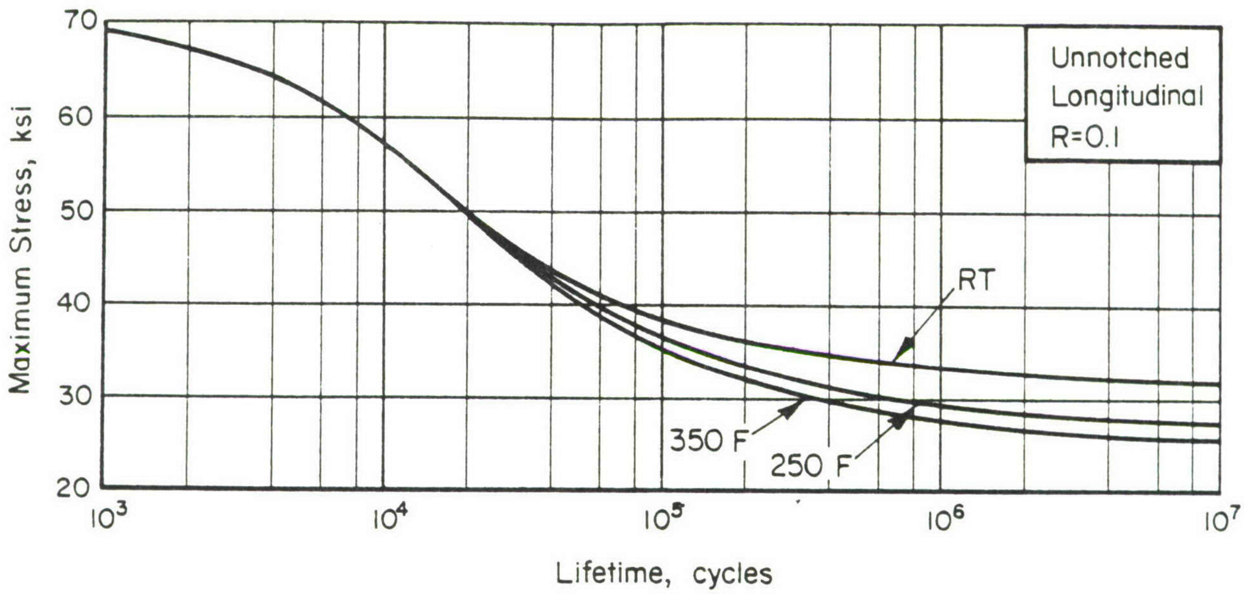


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED X2048-T851 PLATE

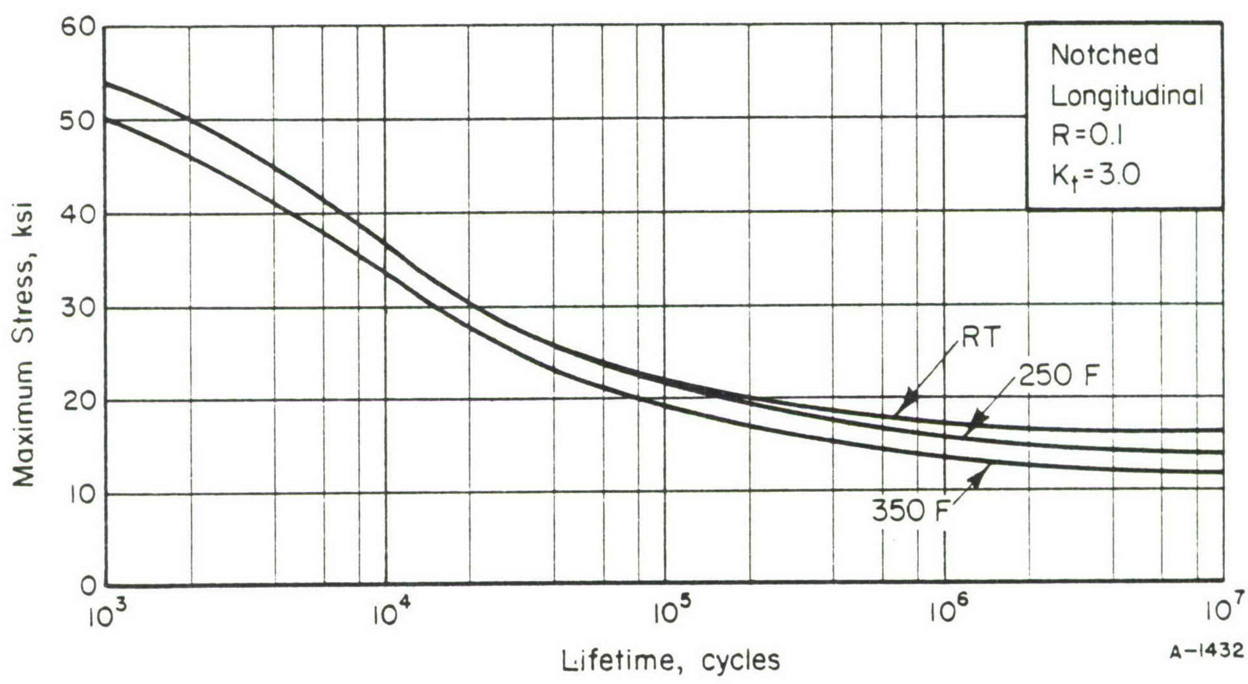


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) X2048-T851 PLATE

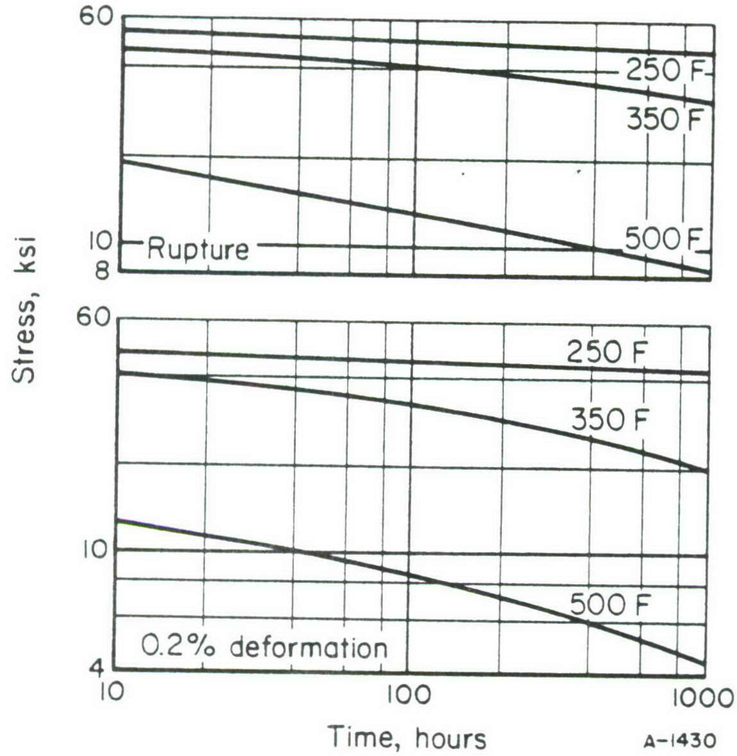


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR X2048-T851 PLATE (LONGITUDINAL)

21-6-9 Stainless Steel Alloy

Material Description

Alloy 21-6-9 is a recent development of the Armco Steel Corporation. It is an austenitic stainless steel, combining high yield strength with good corrosion resistance. The room temperature yield strength of 21-6-9 is superior to Types 304, 321, and 347. It has good elevated temperature properties and retains high strength and toughness at subzero temperatures.

Armco 21-6-9 stainless steel is available in standard finishes in annealed or high tensile temper sheet and strip as well as in bar, wire, forging billets, and plate.

The material used in this evaluation was an 0.072-inch thick sheet produced within the following composition limits:

Carbon	0.08 max
Manganese	8.00 - 10.00
Phosphorus	0.060 max
Sulfur	0.030 max
Silicon	1.00 max
Chromium	19.00 - 21.50
Nickel	5.50 - 7.50
Nitrogen	0.15 - 0.40
Iron	Balance .

Processing and Heat Treating

The alloy was evaluated in the as-received annealed condition.

21-6-9 Stainless Steel Data[a]

Condition: Annealed
Thickness: 0.072-inch sheet

Properties	Temperature, F			
	RT	400	700	900
Tension				
TUS (longitudinal), ksi	113.0	88.1	83.7	76.1
TUS (transverse), ksi	113.3	88.4	83.2	76.5
TYS (longitudinal), ksi	64.8	42.5	35.9	33.0
TYS (transverse), ksi	65.7	42.7	35.9	33.2
e (longitudinal), percent in 2 in.	55.0	43.5	45.6	43.0
e (transverse), percent in 2 in.	50.0	42.0	41.8	41.3
E (longitudinal), 10^6 psi	26.6	21.1	21.7	19.2
E (transverse), 10^6 psi	28.4	19.9	18.4	16.3
Compression				
CYS (longitudinal), ksi	67.2	45.1	40.5	34.7
CYS (transverse), ksi	66.5	46.3	37.9	34.1
E_c (longitudinal), 10^6 psi	28.5	26.7	25.8	25.3
E_c (transverse), 10^6 psi	29.0	28.8	26.5	25.7
Shear[b]				
SUS (longitudinal), ksi	102.3	U[c]	U	U
SUS (transverse), ksi	102.8	U	U	U
Bend[d]				
Minimum Radius	1T	U	U	U
Fracture Toughness				
K_c, T-L, ksi$\sqrt{\text{in.}}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	106	90	80	U
10^5 cycles, ksi	92	82	74	U
10^7 cycles, ksi	68	75	68	U

Properties	Temperature, F RT	400	700	900
Axial Fatigue (transverse) (continued)				
Notched, $K_t = 3.0$, $R = 0.1$				
10^3 cycles, ksi	80	75	75	U
10^5 cycles, ksi	61	44	44	U
10^7 cycles, ksi	46	36	36	U
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA(c)	40	33	31
0.2% plastic deformation, 100 hr, ksi	NA	36	32	30
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	85	83	72
Rupture, 1000 hr, ksi	NA	84	82	64
Stress Corrosion(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
10.6×10^{-6} in/in/F (80-1000 F)				
Density				
0.283 lb/in^3				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Sheet-shear type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Specimens tested from RT to -40 F. No cracks.

(e) Transverse specimens were full sheet thickness by 18 inches wide by 36 inches long with an EDM flaw in the center. The net section yield stress was greater than the tensile yield strength of the material; therefore, the K values obtained are considered <u>not valid</u>.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

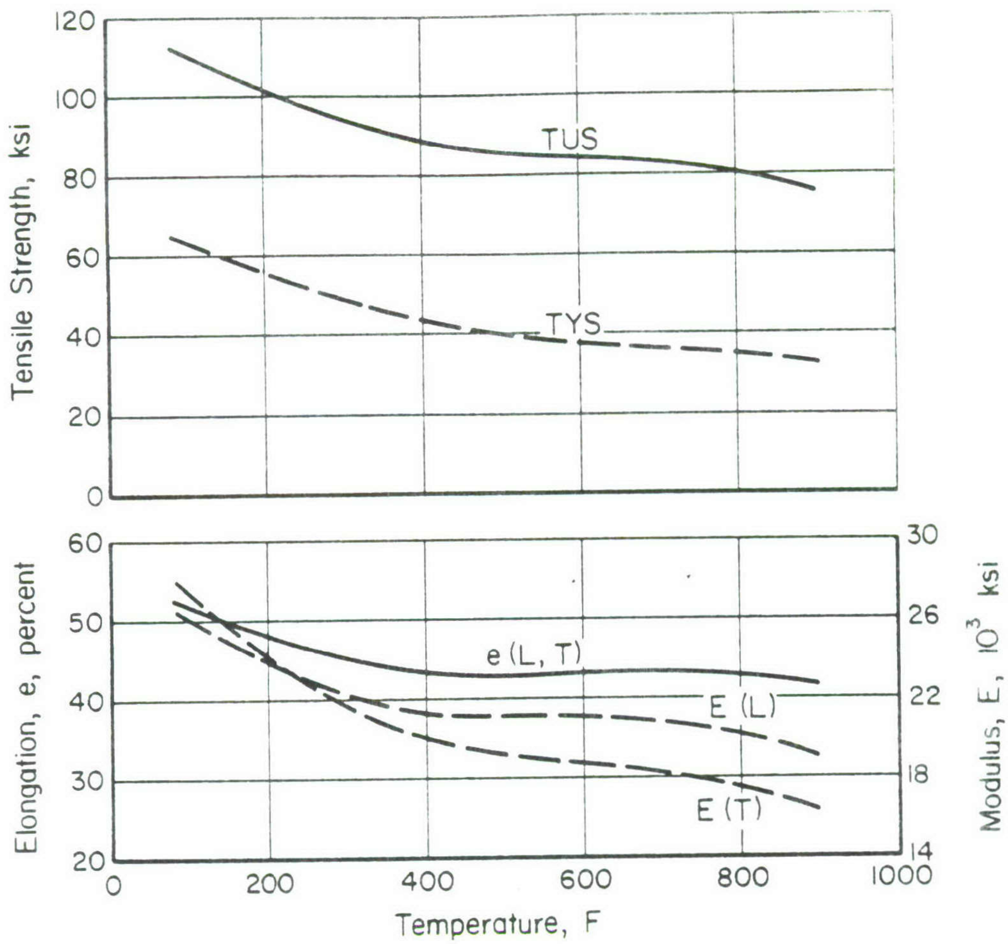


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED 21-6-9 STAINLESS STEEL SHEET

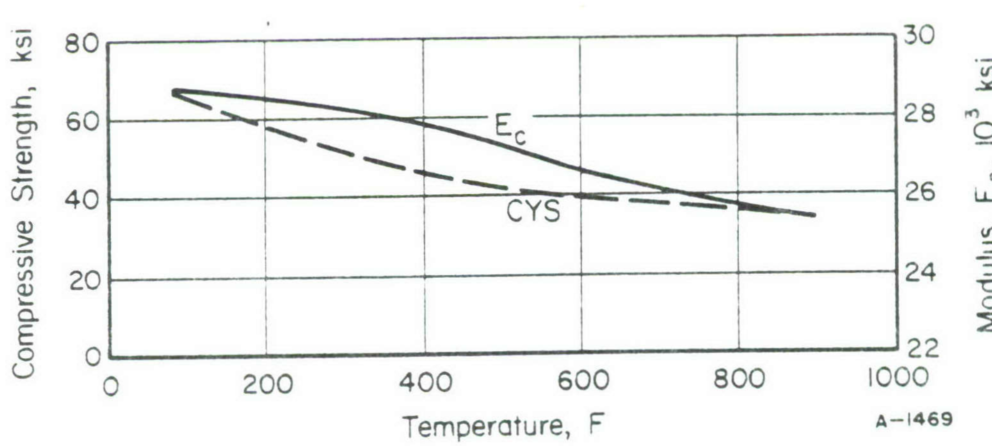


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ANNEALED 21-6-9 STAINLESS STEEL SHEET

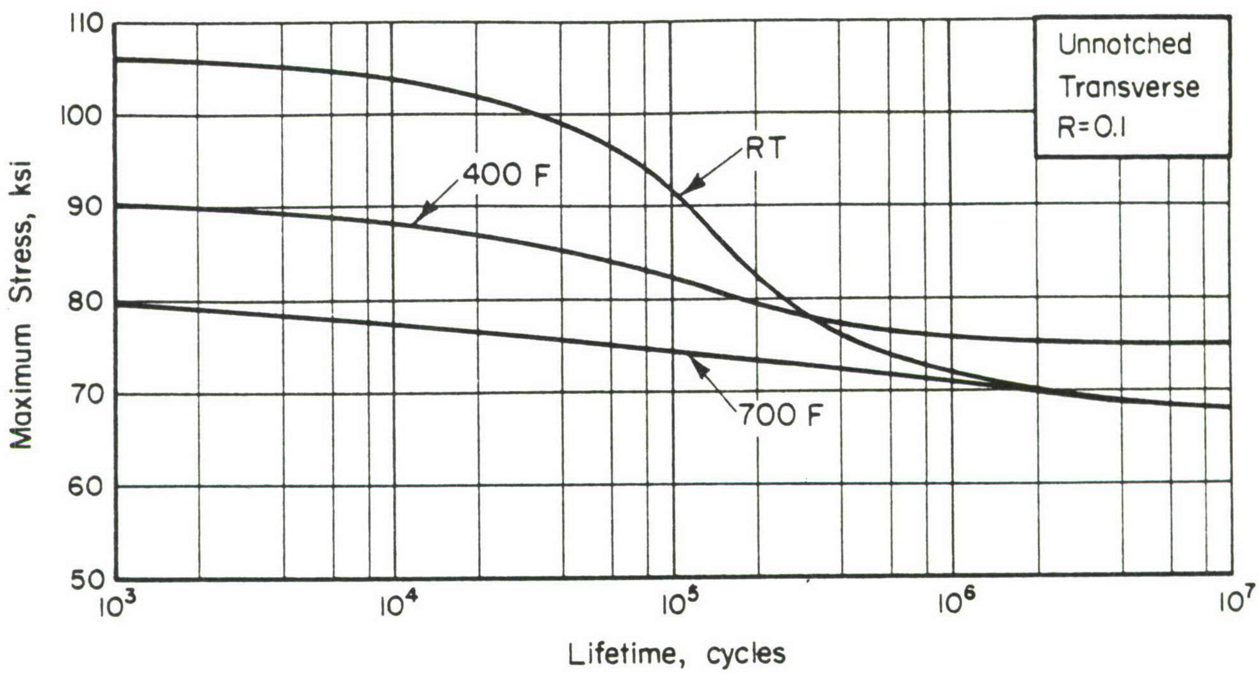


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ANNEALED 21-6-9 STAINLESS STEEL SHEET

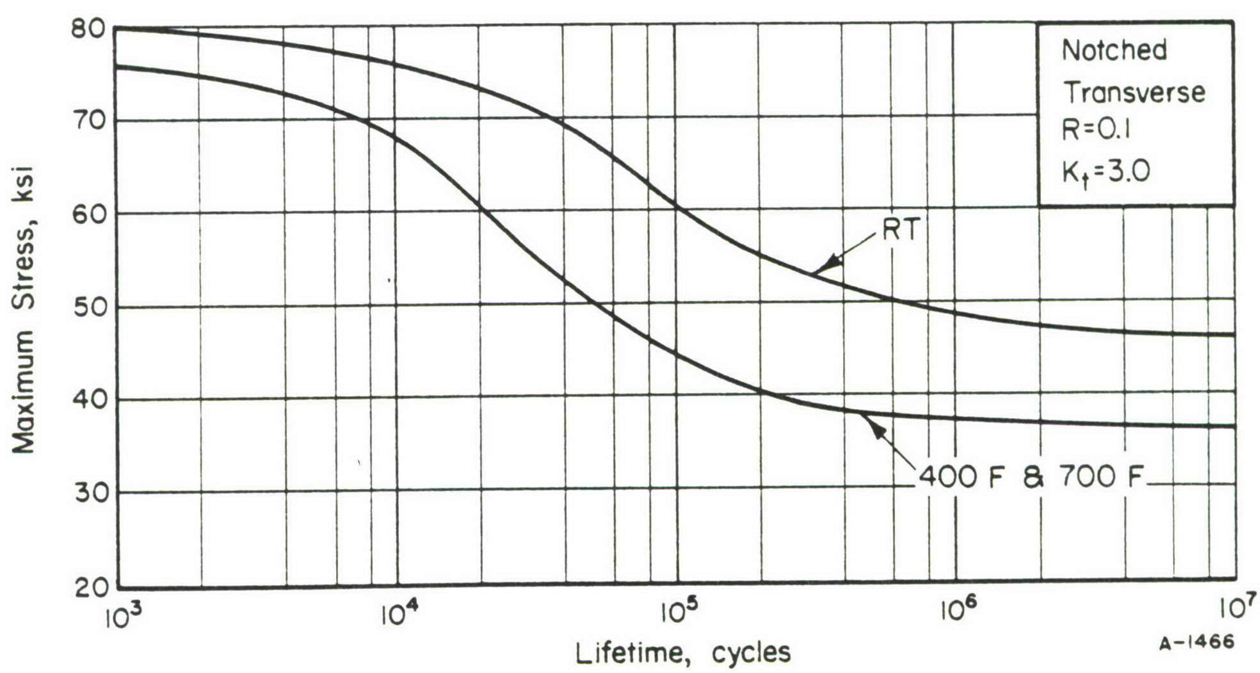


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) ANNEALED 21-6-9 STAINLESS STEEL SHEET

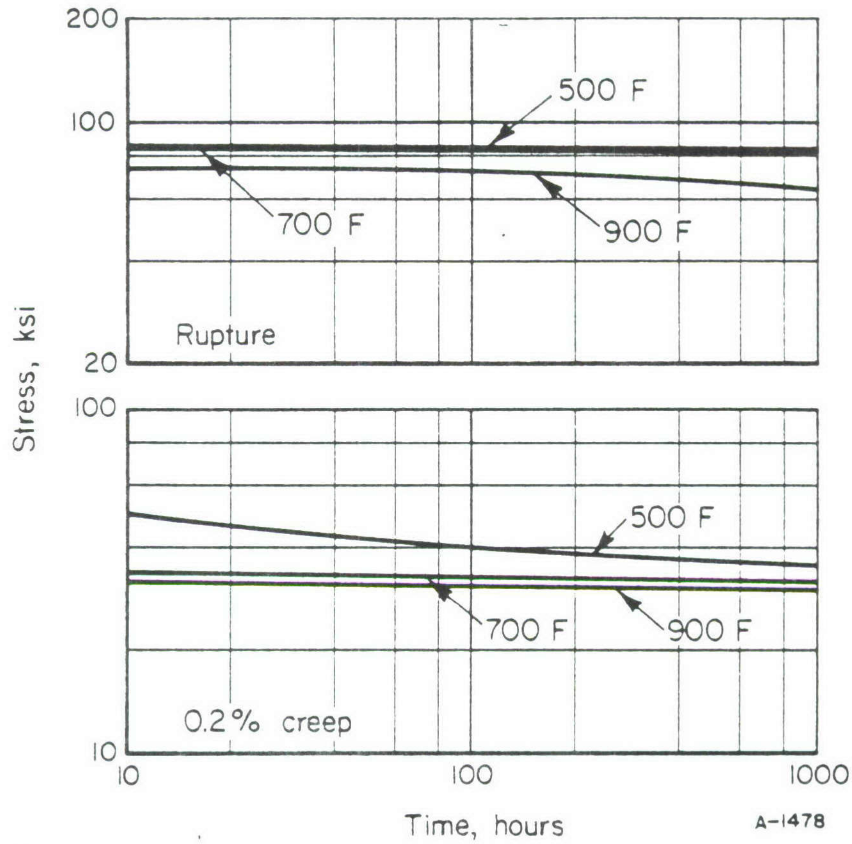


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR ANNEALED 21-6-9 STAINLESS STEEL SHEET

Ti-8Mo-8V-2Fe-3Al Alloy

Material Description

The 8Mo-8V-2Fe-3Al beta titanium alloy is a recent development of TIMET. The alloy was selected for full-scale evaluation after confirming (by TIMET) that it could be melted by the conventional consumable electrode vacuum arc process. It shows producibility and property characteristics that make it suitable for a variety of airframe applications. A variety of heat treatments are available to allow the designer to take advantage of its individual properties or its generally good overall properties. Its short aging times and low density make it particularly desirable for some applications.

The material used in this evaluation was from TIMET Heat K-5055 and was analyzed as follows:

Molybdenum	8.0
Vanadium	8.2
Iron	2.0
Aluminum	3.0
Oxygen	0.14
Nitrogen	0.011
Titanium	Balance .

Processing and Heat Treating

The material was received in the solution treated condition. Specimens were aged at 900 F for 6 hours. This condition is called the high strength, fully-aged condition.

Ti-8Mo-8V-2Fe-3Al Alloy Data[a]

Condition: Solution treated and aged (900 F)
Thickness: 0.040-inch sheet

Properties	Temperature, F			
	RT	400	600	800
Tension				
TUS (longitudinal), ksi	160.3	148.7	146.0	137.7
TUS (transverse), ksi	174.7	155.3	152.3	141.0
TYS (longitudinal), ksi	144.7	123.3	117.7	105.7
TYS (transverse), ksi	158.0	133.3	124.0	112.7
e (longitudinal), percent in 2 in.	11.7	9.0	7.3	18.7
e (transverse), percent in 2 in.	9.5	6.8	6.7	16.2
E (longitudinal), 10^6 psi	13.6	13.3	12.4	11.8
E (transverse), 10^6 psi	14.9	14.1	13.2	12.3
Compression				
CYS (longitudinal), ksi	177.7	140.7	138.7	134.7
CYS (transverse), ksi	191.7	163.7	151.7	138.7
E_c (longitudinal), 10^6 psi	15.9	14.5	14.2	12.7
E_c (transverse), 10^6 psi	16.9	16.1	14.8	13.6
Shear[b]				
SUS (longitudinal), ksi	100.5	U[c]	U	U
SUS (transverse), ksi	106.8	U	U	U
Fracture Toughness[d]				
K_c, T-L, ksi$\sqrt{\text{in.}}$	48	U	U	U
Axial Fatigue (Transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	138	138	130	U
10^5 cycles, ksi	74	74	67	U
10^7 cycles, ksi	63	63	60	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	109	109	98	U
10^5 cycles, ksi	30	30	26	U
10^7 cycles, ksi	22	22	20	U

Ti-8Mo-8V-2Fe-3Al Alloy Data
(continued)

Properties	RT	Temperature, F 550	700	900
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	70	27	7
0.2% plastic deformation, 1000 hr, ksi	NA	40	20	3
Stress Rupture (Transverse)				
Rupture 100 hr, ksi	NA	149	144	43
Rupture 1000 hr, ksi	NA	147	100	26
Stress Corrosion(f)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
5.0×10^{-6} in./in./F (RT to 800 F)				
Density				
0.175 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Sheet-shear type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Transverse specimens were full sheet thickness by 18 inches wide by 36 inches long with an EDM flaw in the center.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is $R = S_{min}/S_{max}$ "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

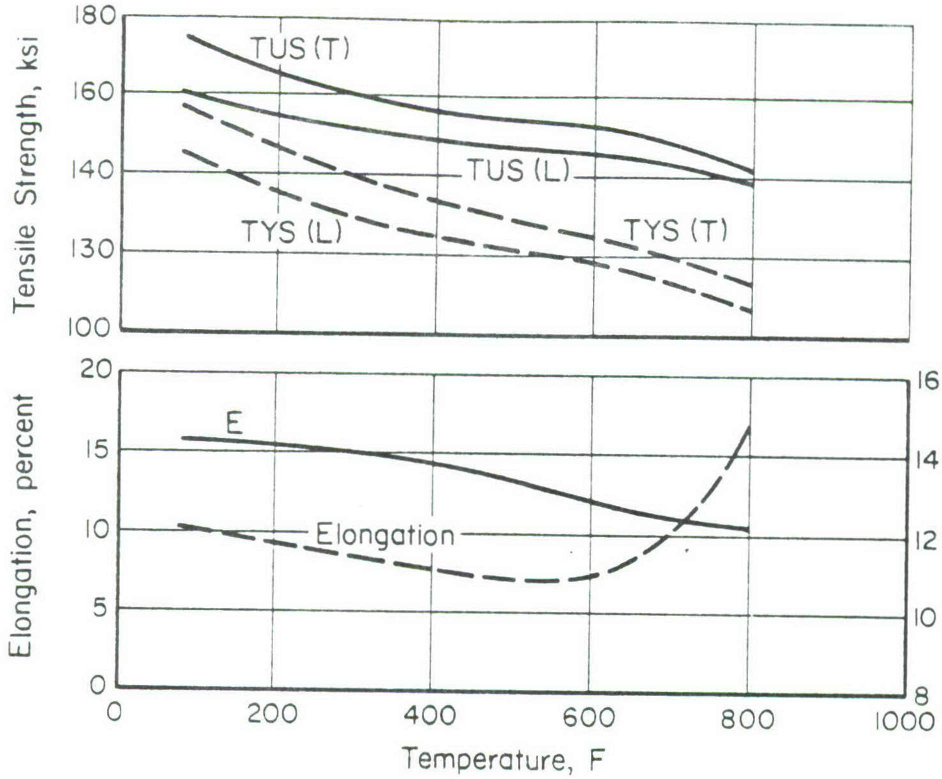


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

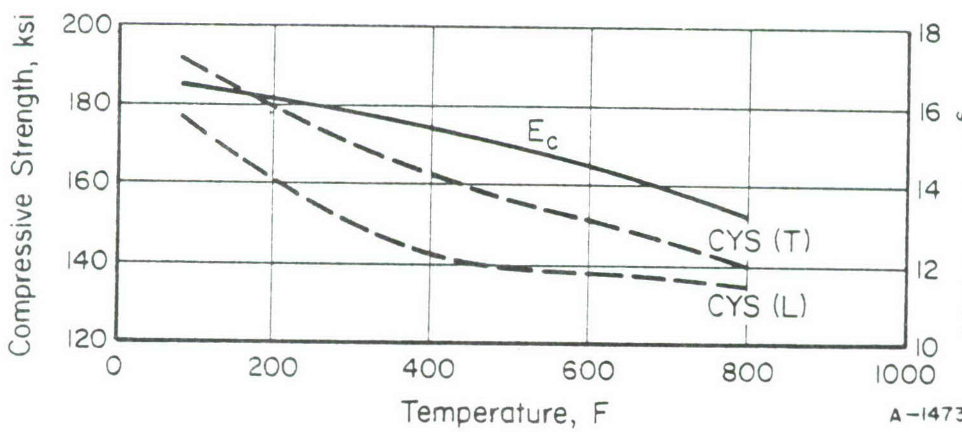


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

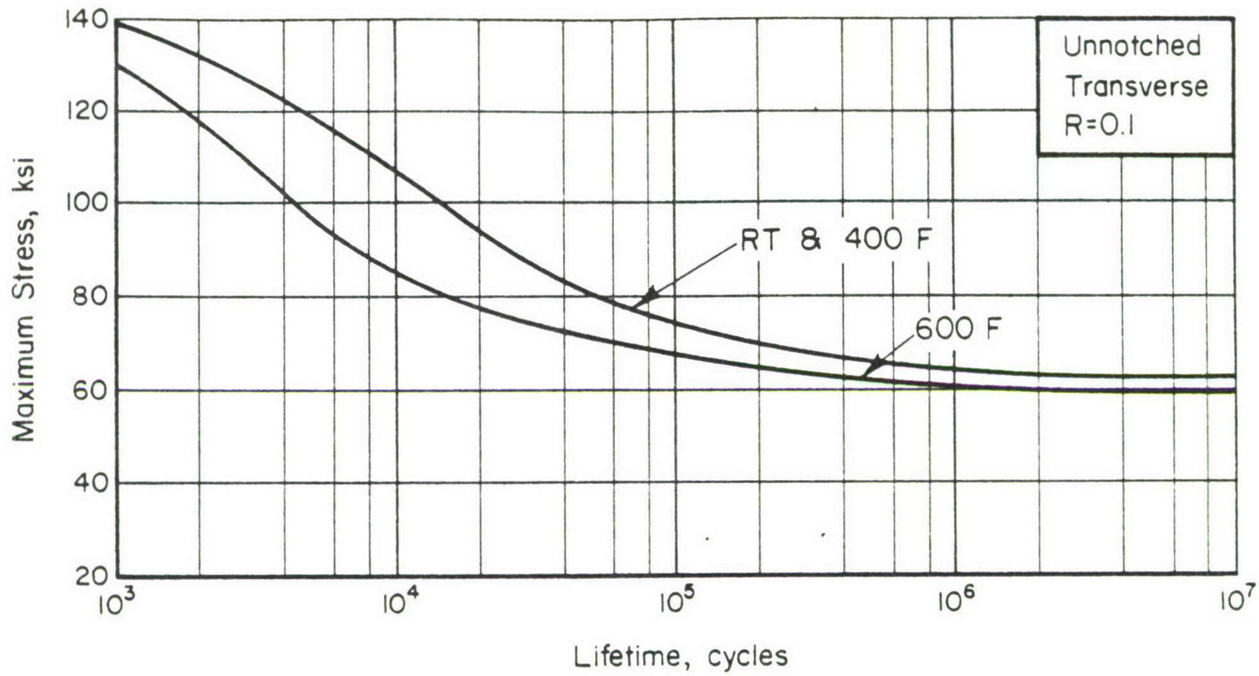


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

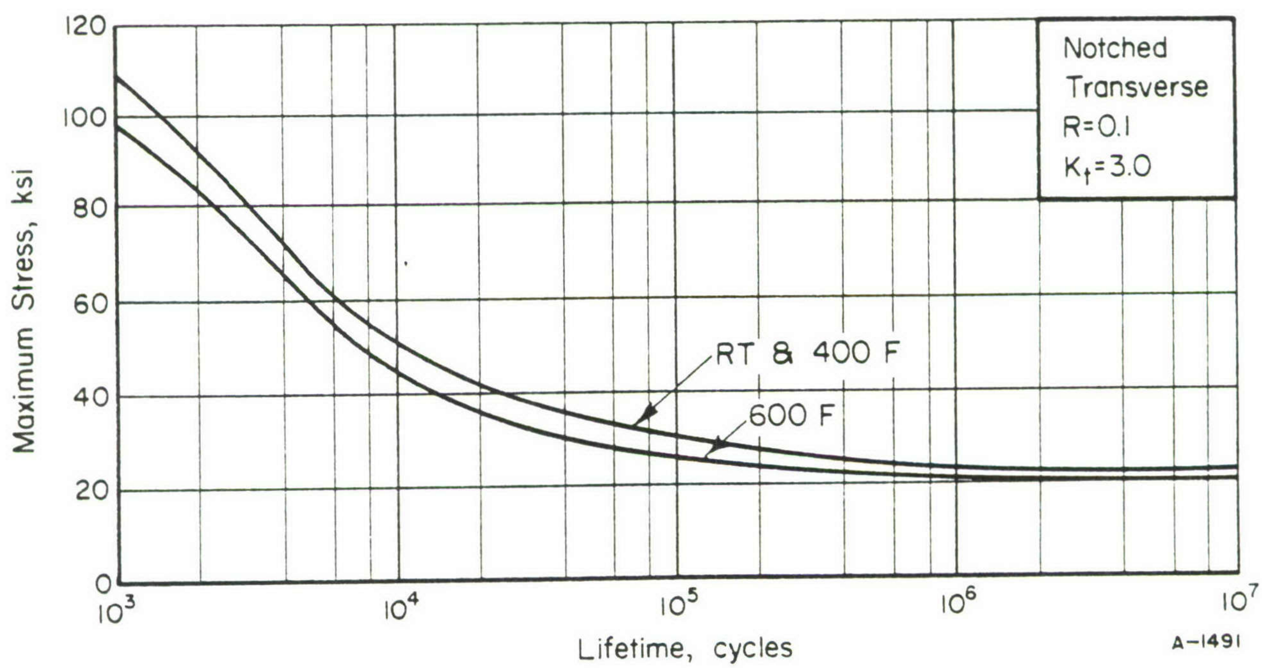


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

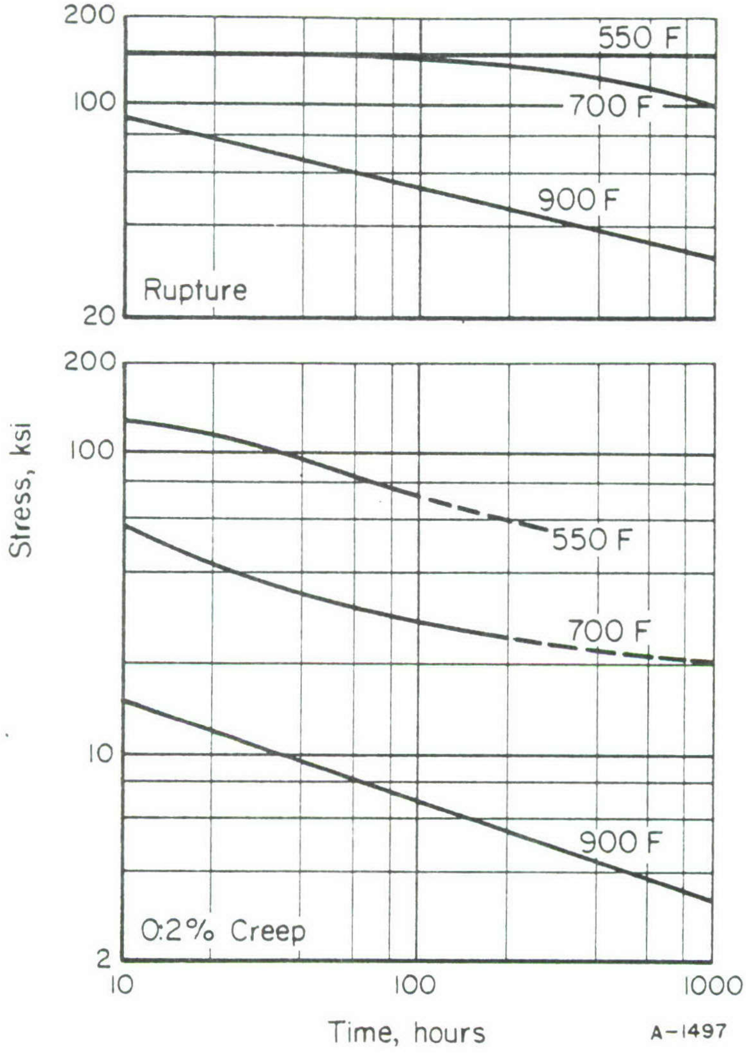


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

Ti-6Al-6V-2Sn Isothermal Die Forgings

Material Description

This is a heat-treatable alpha beta type alloy similar in many respects to Ti-6Al-4V, but containing increased content of beta stabilizing elements which provide higher strength potential.

The material used for this evaluation was made by IIT Research Institute under Air Force Contract F33615-67-C-1722. It consisted of structural shapes and nose wheels that were isothermally creep (slow speed) forged from flat preforms machined from conventionally forged Ti-6Al-6V-2Sn alloy billets.

Processing and Heat Treating

The material was received with no heat treatment after forging. Specimens were solution treated at 1650 F for 1/2 hour, water quenched, and aged at 1050 F for 4 hours and air cooled. This treatment was as suggested by IIT Research Institute.

Ti-6Al-6V-2Sn Alloy Data[a]

Condition: Solution treated and aged
Thickness: Die forging of varying thickness

Properties	Temperature, F RT	400	700	900
Tension				
TUS (transverse), ksi	202.5	170.4	158.4	133.6
TYS (transverse), ksi	192.9	153.2	131.8	80.3
e (transverse), percent in 1 in.	4.7	7.7	8.3	22.0
E (transverse), 10^6 psi	16.0	14.7	13.1	12.1
Compression				
CYS (transverse), ksi	199.3	174.3	152.9	107.7
E_c (transverse), 10^6 psi	18.0	16.1	13.2	11.9
Shear[b]				
SUS (longitudinal), ksi	131.6	U[c]	U	U
SUS (transverse), ksi	130.0	U	U	U
Impact[d]				
V-notch Charpy, ft. lbs.				
(longitudinal)	11.7	U	U	U
(transverse)	8.5	U	U	U
Fracture Toughness[e]				
K_{Ic}, L-T, ksi$\sqrt{in.}$	25.0	U	U	U
K_{Ic}, T-L, ksi$\sqrt{in.}$	26.7	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	112	112	112	U
10^5 cycles, ksi	50	42	50	U
10^7 cycles, ksi	42	32	42	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	76	76	76	U
10^5 cycles, ksi	43	43	43	U
10^7 cycles, ksi	26	30	32	U
Creep (transverse)				
0.2% plastic deformation, 100 hr., ksi	NA[c]	NA	48	5
0.2% plastic deformation, 1000 hr., ksi	NA	NA	27	3

Ti-6Al-6V-2Sn Alloy Data
(Continued)

Properties	Temperature, F RT	400	700	900
Stress-Rupture (transverse)				
Rupture, 100 hr., ksi	NA	NA	130	45
Rupture, 1000 hr., ksi	NA	NA	115	36
Stress Corrosion[(g)]				
80% TYS, 1000 hr. maximum	no cracks			
Coefficient of Thermal Expansion				
5.3×10^{-6} in./in./F (68 F to 900 F)				
Density				
0.164 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of 4 tests in each direction.

(e) Results of tests at AFML on compact tension specimens.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

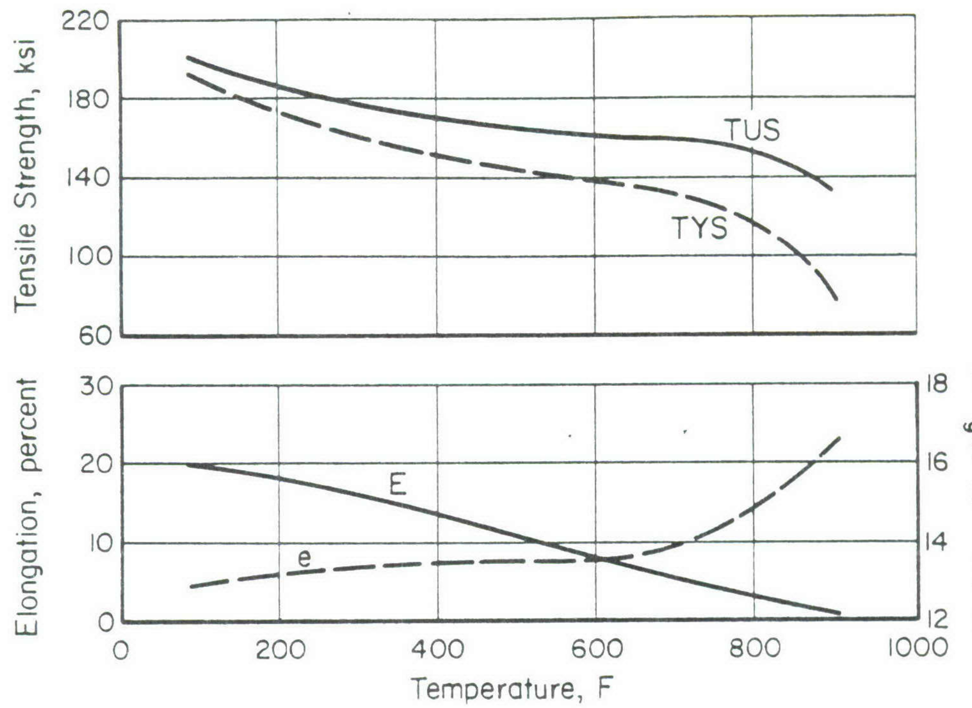


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

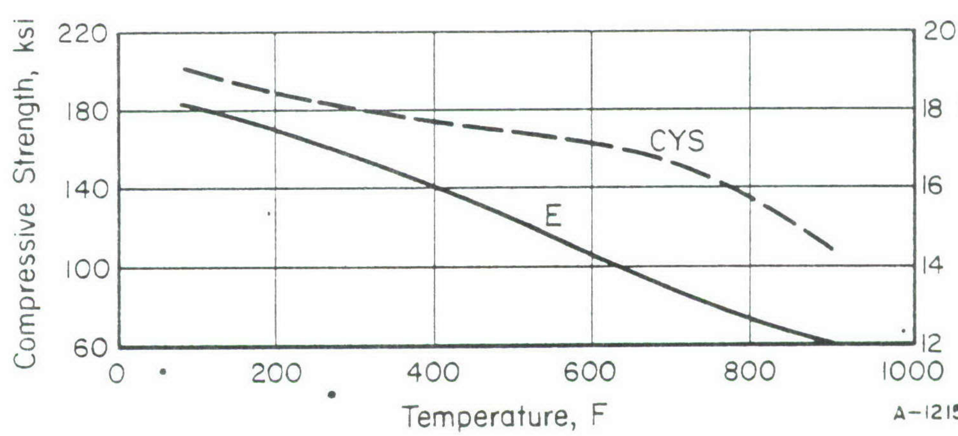


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

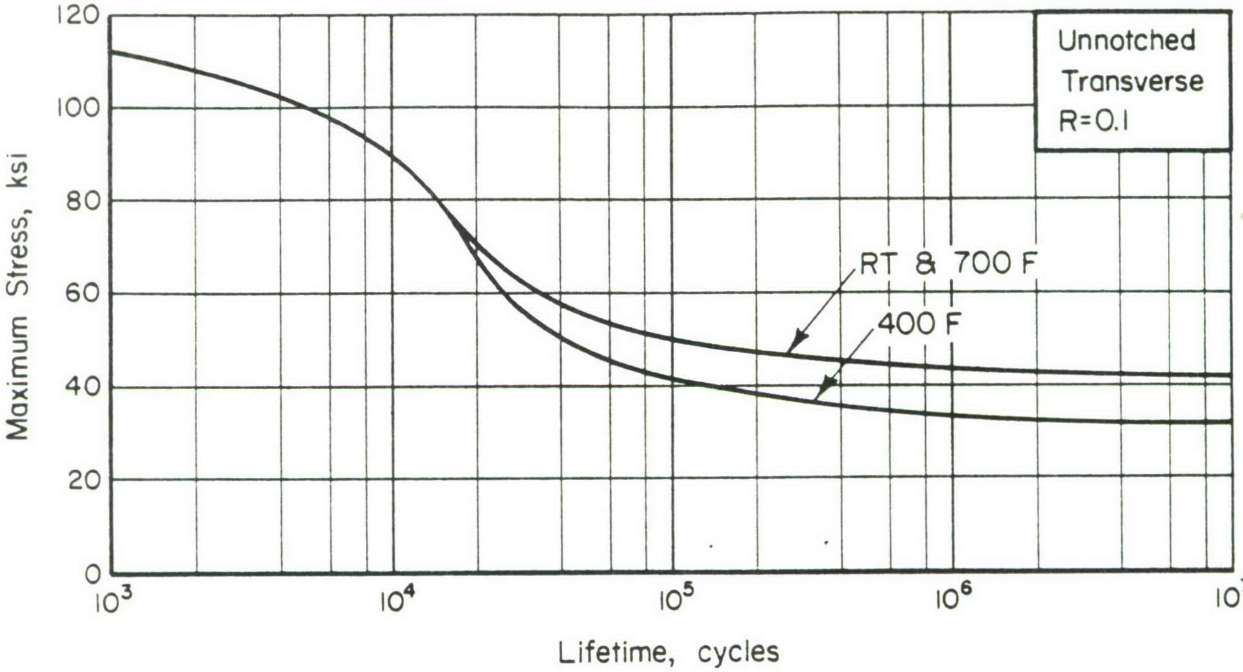


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

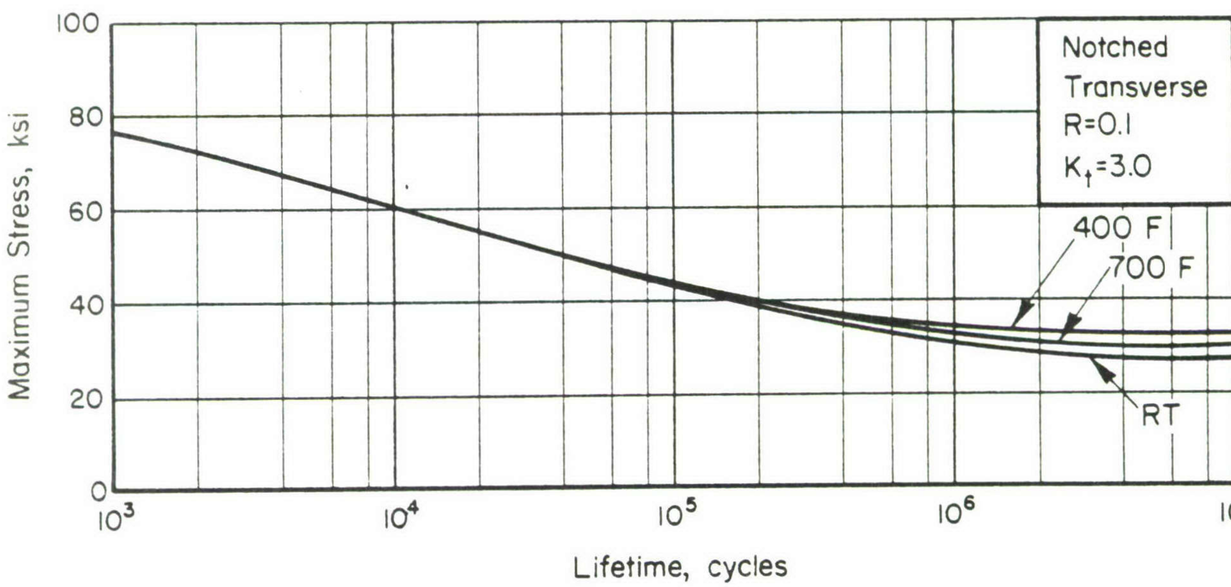


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

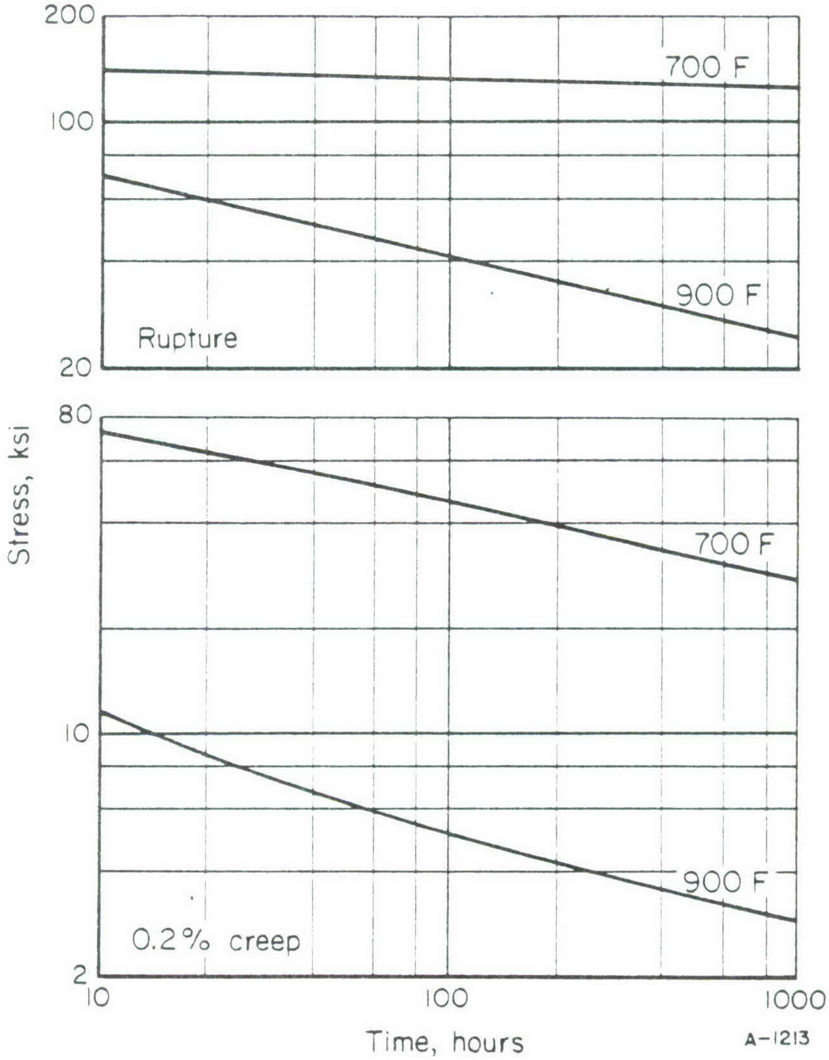


FIGURE 5. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)

Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy

Material Description

This alloy is a recent development of RMI Company. It is an alpha-beta type alloy designed for deep hardenability. Preliminary information shows the material to have low density, high modulus, high toughness, and good producibility. Strength retention to 800 F is good.

The material used for this evaluation was a 1 1/2-inch thick plate from RMI ingot number 890180 which had the following chemistry:

Al	5.8
Sn	2.1
Zr	1.8
Mo	2.0
Cr	1.9
Si	0.21
Fe	0.06
C	0.02
N_2	0.010
O_2	0.011

Additional information on this alloy is available on work performed by RMI Company under Wright Field Air Force Contract F33615-72-C-1152.

Processing and Heat Treating

The plate product evaluated was alpha beta processed to develop a refined microstructure. The plate was received in the solution-treated condition (1740 F, 1 hour, Air Cooled) condition. Specimens were then aged at 1000 F for 8 hours. It should be noted that heavier sections require oil or water quench to effectively solution treat the product.

Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY DATA[a]

Condition: solution treated and aged
Thickness: 1 1/2 inch plate

Properties	Temperature, F RT	400	600	800
Tension				
TUS (longitudinal), ksi	168.3	145.3	139.0	132.0
TUS (transverse), ksi	168.7	146.0	139.7	132.0
TYS (longitudinal), ksi	155.6	116.0	107.0	101.2
TYS (transverse), ksi	156.6	119.7	108.7	104.0
e (longitudinal), percent in 1 in.	18.0	19.5	18.5	21.3
e (transverse), percent in 1 in.	17.7	19.7	18.2	21.0
RA (longitudinal), percent	24.8	33.2	34.9	42.1
RA (transverse), percent	26.2	33.7	33.3	41.4
E (longitudinal), 10^6 psi	17.9	15.9	15.6	14.4
E (transverse), 10^6 psi	17.8	16.2	16.0	14.6
Compression				
CYS (longitudinal), ksi	169.7	128.3	112.0	105.7
CYS (transverse), ksi	173.3	129.3	115.0	106.3
E_c (longitudinal), 10^6	18.1	16.7	15.8	14.6
E_c (transverse), 10^6 psi	18.5	16.3	15.8	14.6
Shear[b]				
SUS (longitudinal), ksi	108.3	U[c]	U	U
SUS (transverse), ksi	108.0	U	U	U
Impact[d]				
V-notch Charpy, Ft. lb.				
(longitudinal)	13.9	U	U	U
(transverse)	16.3	U	U	U
Fracture Toughness[e]				
K_{Ic}, L-T, ksi $\sqrt{in.}$	88.0	U	U	U
K_{Ic}, T-L, ksi $\sqrt{in.}$	93.0	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R=0.1				
10^3 cycles, ksi	168	150	134	U
10^5 cycles, ksi	135	123	116	U
10^7 cycles, ksi	75	75	75	U
Notched, K_t=3.0, R=0.1				
10^3 cycles, ksi	126	102	90	U
10^5 cycles, ksi	60	55	50	U
10^7 cycles, ksi	42	37	37	U

Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY DATA
(Continued)

Properties	RT	Temperature, F 400	600	800
Creep (transverse)				
0.2% plastic deformation, 100 hr., ksi	NA	122	120	83
0.2% plastic deformation, 1000 hr., ksi	NA	118	115	60
Stress-Rupture (transverse)				
Rupture, 100 hr., ksi	NA	142	132	122
Rupture, 1000 hr., ksi	NA	141	131	119
Stress Corrosion(g)				
80% TYS, 1000 hr. maximum	no cracks			
Coefficient of Thermal Expansion				
5.1×10^{-6} in./in./F (68 to 800 F)				
Density				
0.165 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Values are average of 6 tests in each direction.

(e) These values do not meet the rigorous $A_1 T_1 < 2.5 \left(\frac{K_Q}{TYS}\right)^2$ criteria. However, they are over $2.2 \left(\frac{K_Q}{TYS}\right)^2$ and should be considered good indicative K_{Ic} values.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

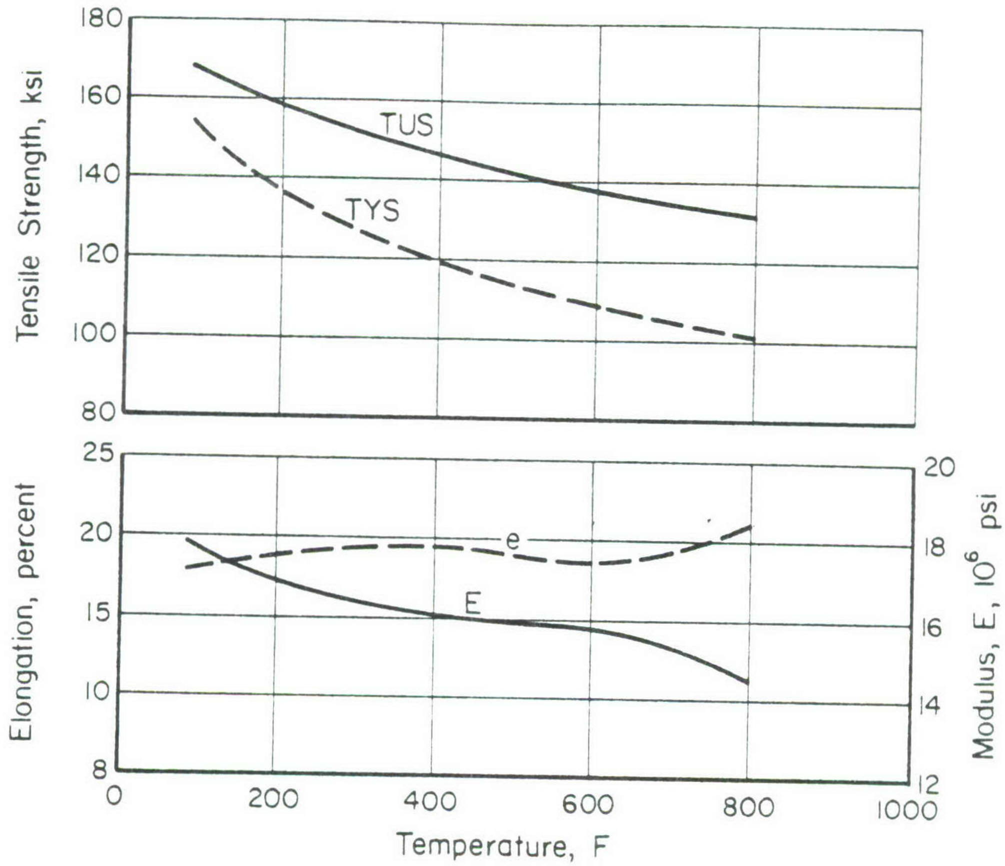


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

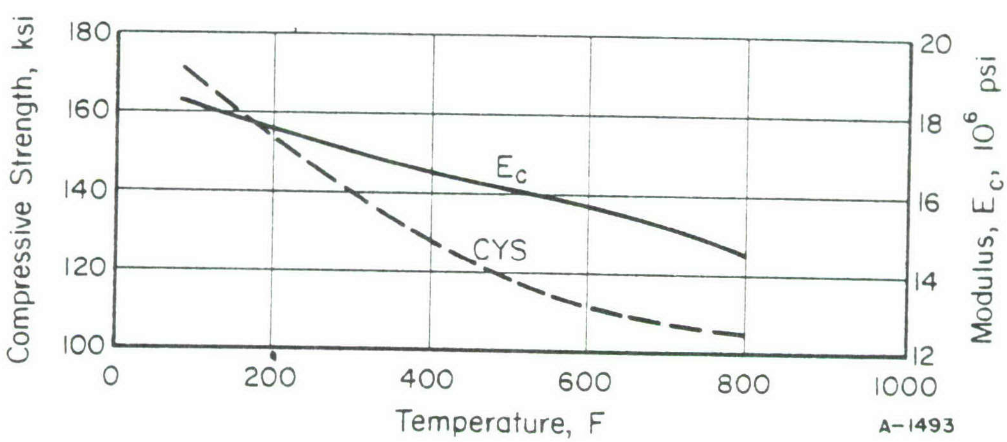


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

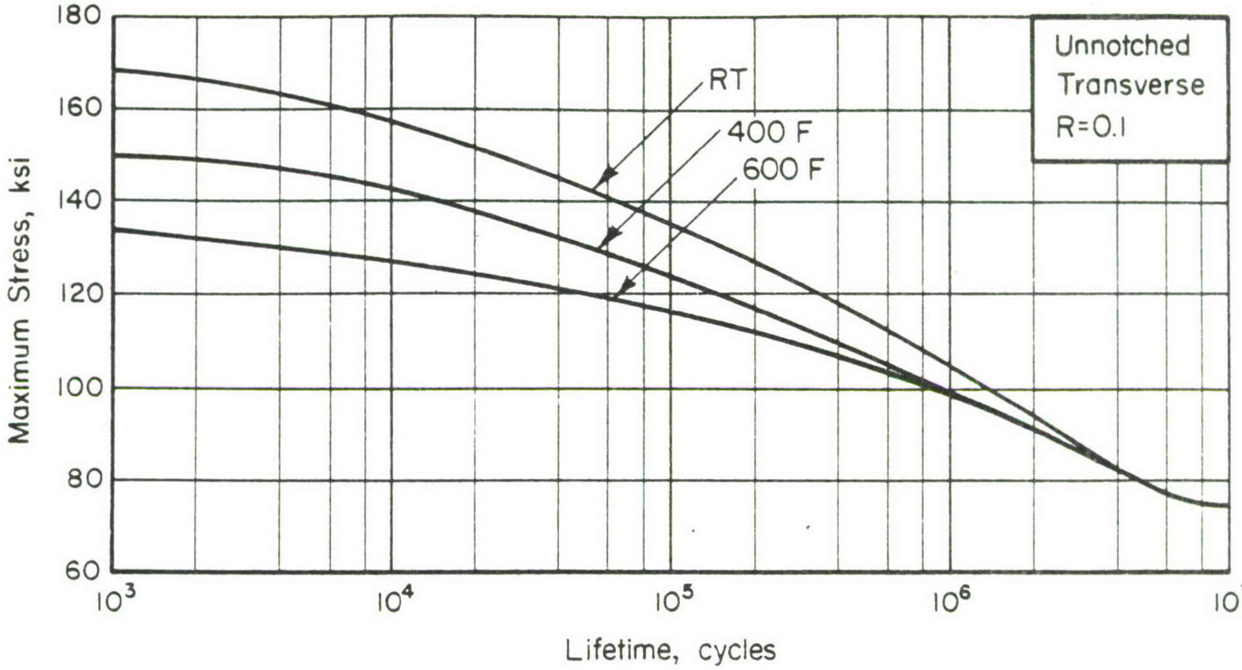


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

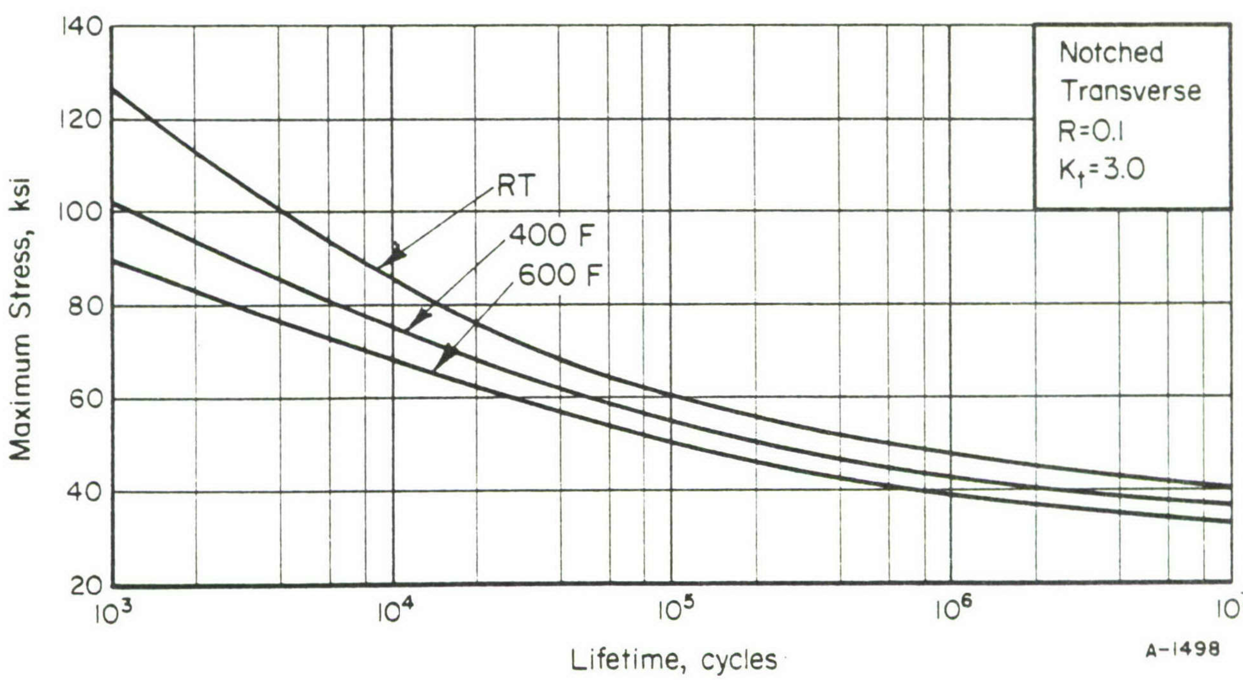


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

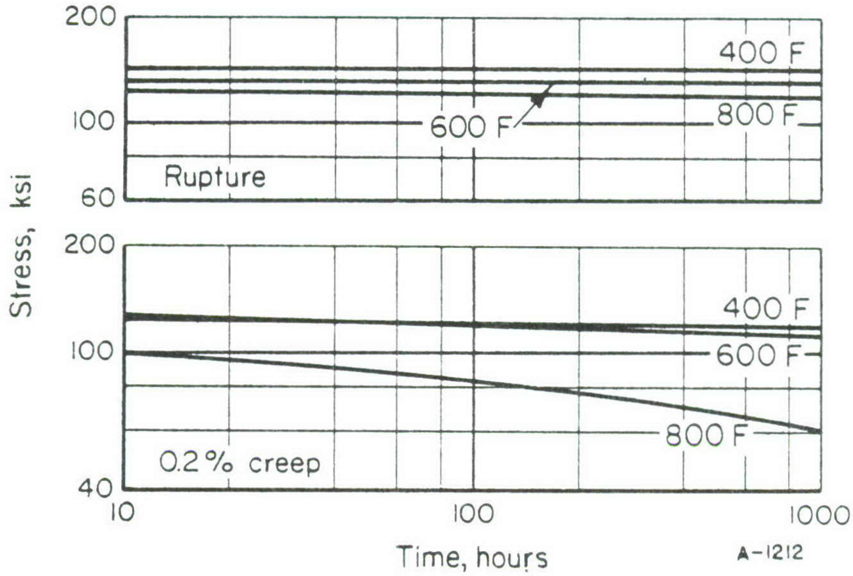


FIGURE 5. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

7050-T73651 Aluminum Alloy

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was 1-inch plate from Heat S-416420 produced within the following composition limits:

Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance .

Processing and Heat Treating

Specimens were tested in the as-received -T73651 temper.

7050-T73651 Aluminum Alloy Data[a]

Thickness: 1-inch plate

Properties	RT	250	350	500
	Temperature, F			
Tension				
TUS (longitudinal), ksi	82.6	65.0	53.7	21.2
TUS (transverse), ksi	81.5	64.5	53.5	20.9
TYS (longitudinal), ksi	73.8	64.9	53.5	20.9
TYS (transverse), ksi	72.5	64.1	53.3	20.8
e (longitudinal), percent in 2 in.	11.7	15.5	16.8	23.8
e (transverse), percent in 2 in.	10.5	13.3	14.7	23.5
RA (longitudinal), percent	30.2	48.1	58.1	81.0
RA (transverse), percent	24.5	38.7	47.8	79.8
E (longitudinal), 10^6 psi	10.3	9.4	8.7	8.4
E (transverse), 10^6 psi	10.5	9.7	8.7	8.7
Compression				
CYS (longitudinal), ksi	73.0	64.3	53.7	20.9
CYS (transverse), ksi	75.3	66.1	55.1	22.0
E_c (longitudinal), 10^6 psi	10.8	9.5	9.1	8.1
E_c (transverse), 10^6 psi	11.0	10.0	9.4	8.0
Shear[b]				
SUS (longitudinal), ksi	48.7	U[c]	U	U
SUS (transverse), ksi	47.9	U	U	U
Impact[d]				
V-notch Charpy, ft. lb.				
(longitudinal)	34.7	U	U	U
(transverse)	5.7	U	U	U
Fracture Toughness[e]				
K_{Ic}, L-T, ksi $\sqrt{in.}$	37.7	U	U	U
K_{Ic}, L-T, ksi $\sqrt{in.}$	36.9	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	69	65	63	U
10^5 cycles, ksi	42	37	34	U
10^7 cycles, ksi	31	23	20	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	45	44	43	U
10^5 cycles, ksi	19	18	16	U
10^7 cycles, ksi	12	11	10	U

Properties	RT	Temperature, F 250	350	500
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA[c]	49	21	5
0.2% plastic deformation, 1000 hr, ksi	NA	35	13.5	3.5
Stress-Rupture (transverse)				
Rupture, 100 hr, ksi	NA	53	26	7.5
Rupture, 1000 hr, ksi	NA	47	17	4.5
Stress Corrosion[g]				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
12.8×10^{-6} in/in/F (68 to 212 F)				
Density				
0.102 lb/in^3				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests in each direction.

(e) Values are average of 6 slow-bend type tests in each direction. Specimen size was 1.000-inch thick by 2.000 inches wide with a span of 8 inches.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

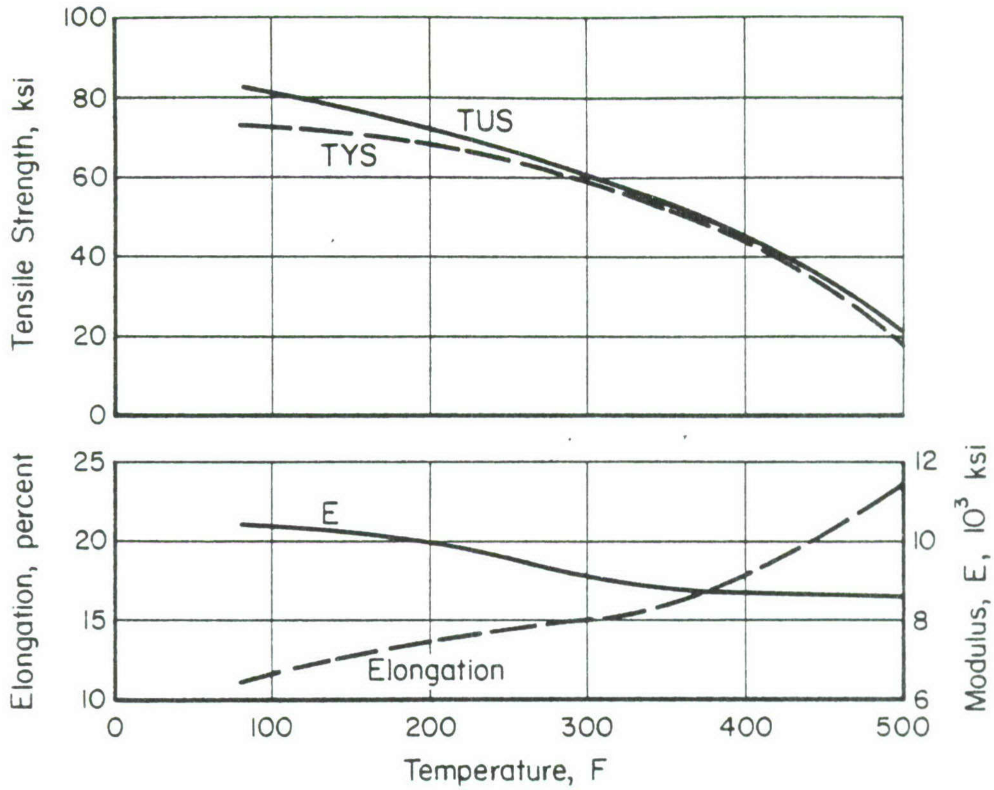


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73651 ALUMINUM ALLOY PLATE

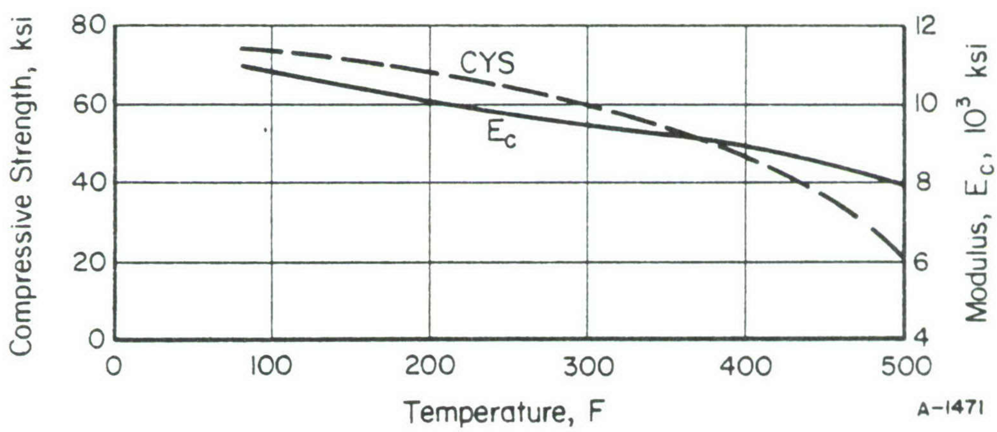


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73651 ALUMINUM ALLOY PLATE

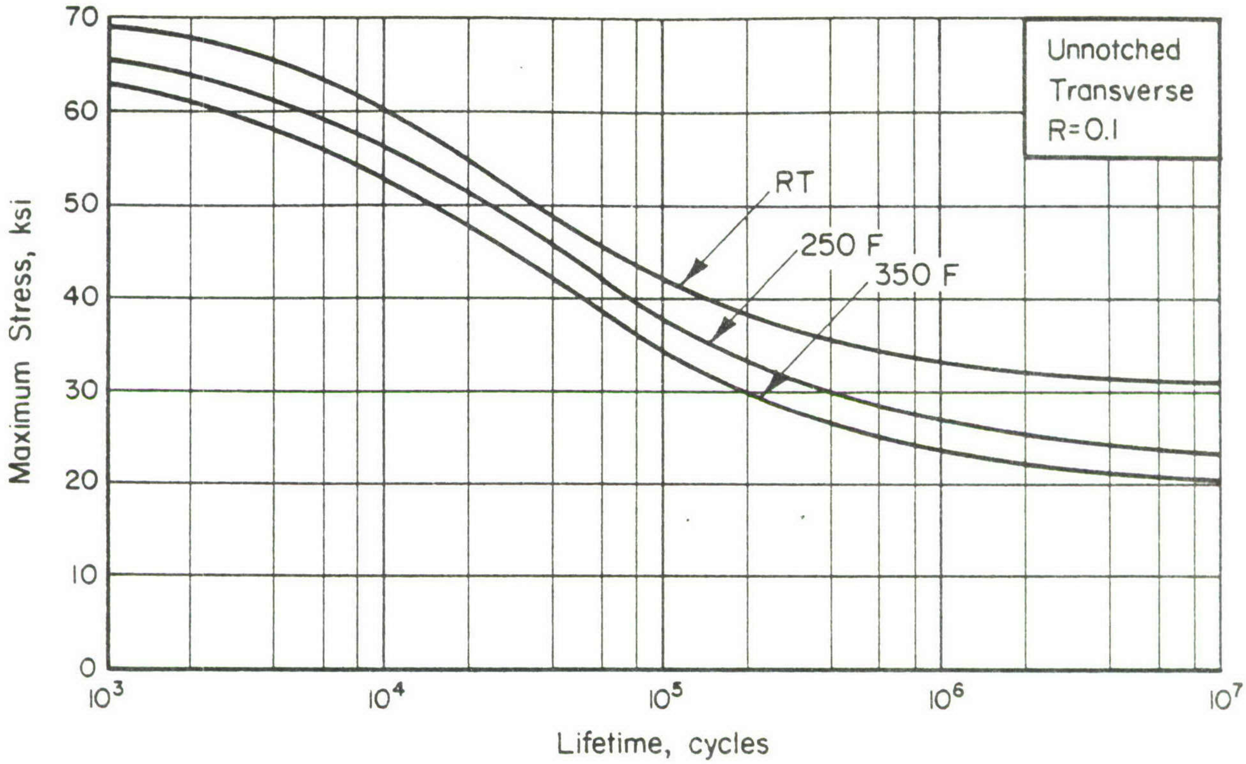


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73651 ALUMINUM PLATE (TRANSVERSE)

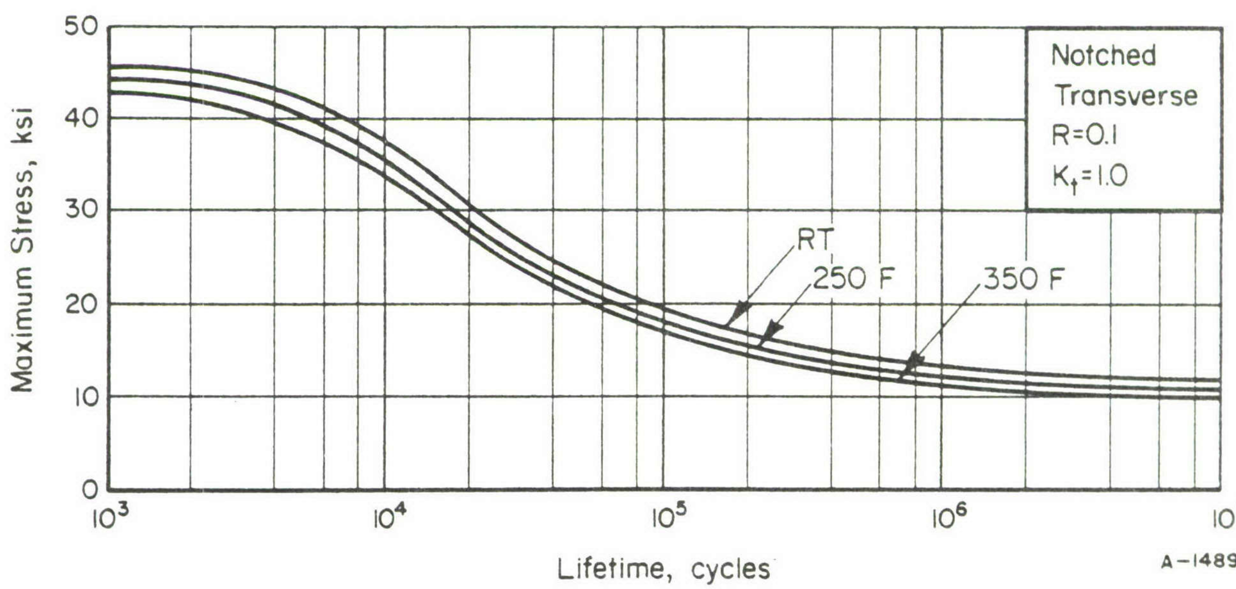


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t=3.0) 7050-T73651 ALUMINUM PLATE (TRANSVERSE)

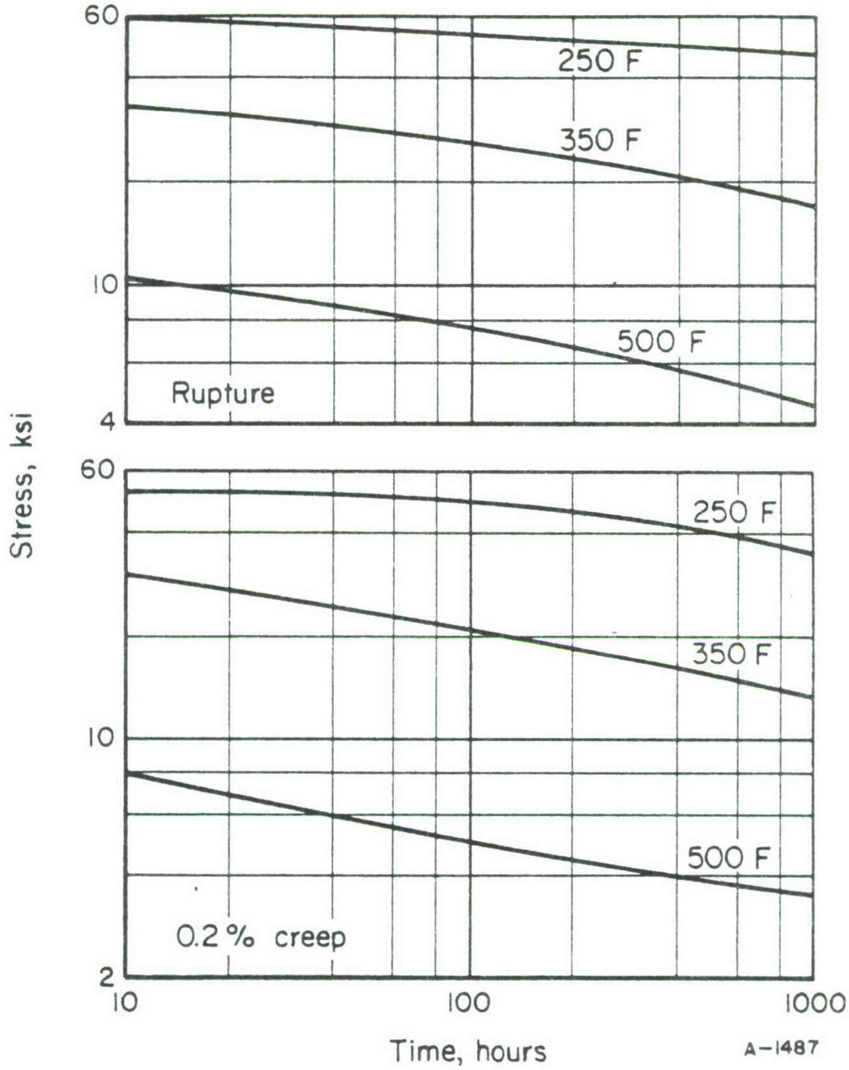


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7050-T73651 ALUMINUM ALLOY PLATE (TRANSVERSE)

7049-T7351 Aluminum Plate

Material Description

Alloy 7049 was developed by Kaiser Aluminum and Chemical Corporation to have a strength level in the range of 7075-T6 and 7079-T6 coupled with a high resistance to stress corrosion cracking. Initial development and production was in the form of forgings and hand forgings. Further development has been in plates and extrusions.

The material evaluated was a 3-inch-thick plate supplied by Kaiser with the following composition:

Chemical Composition	Percent
Zinc	7.6
Magnesium	2.5
Copper	1.5
Chromium	0.15
Silicon	0.25 max
Iron	0.35 max
Titanium	0.10 max
Manganese	0.20 max
Aluminum	Balance

Processing and Heat Treating

Specimens were tested in the as-received -T7351 temper.

7049-T7351 Alloy Data[a]

Thickness: 3-inch plate

Property	RT	250	350	500
	Temperature, F			
Tension				
TUS (longitudinal), ksi	75.5	59.0	45.4	15.1
TUS (transverse), ksi	74.6	60.8	47.0	17.2
TYS (longitudinal), ksi	66.5	58.7	45.1	14.9
TYS (transverse), ksi	64.7	59.5	46.3	17.2
e (longitudinal), percent in 2 in.	13.0	18.2	20.2	31.8
e (transverse), percent in 2 in.	10.7	15.5	17.3	28.8
RA (longitudinal), percent	36.1	53.5	64.9	86.3
RA (transverse), percent	25.6	43.4	54.6	83.2
E (longitudinal), 10^3 ksi	10.2	9.3	8.0	6.0
E (transverse), 10^3 ksi	10.4	9.5	8.4	5.7
Compression				
CYS (longitudinal), ksi	64.1	56.8	44.4	16.7
CYS (transverse), ksi	69.2	59.8	47.5	17.0
E_c (longitudinal), 10^3 ksi	10.8	9.4	8.1	6.9
E_c (transverse), 10^3 ksi	10.9	9.7	8.3	7.0
Shear[b]				
SUS (longitudinal), ksi	46.1	U[c]	U	U
SUS (transverse), ksi	45.4	U	U	U
Impact[d]				
V-notch Charpy, ft.lb.				
(longitudinal)	5.8	U	U	U
(transverse)	3.3	U	U	U
Fracture Toughness[e]				
K_{Ic} (L-T), ksi $\sqrt{\text{in.}}$	34.0	U	U	U
K_{Ic} (T-L), ksi $\sqrt{\text{in.}}$	28.1	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	65	60	47	U
10^5 cycles, ksi	44	39	36	U
10^7 cycles, ksi	35	26	23	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	55	53	53	U
10^5 cycles, ksi	19	17	17	U
10^7 cycles, ksi	11	10	10	U

7049-T7351 Alloy Data
(Continued)

Property	RT	250	350	500
	Temperature, F			
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA(c)	32	11	3
0.2% plastic deformation, 1000 hr, ksi	NA	24	6	2
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	42	18	6
Rupture, 1000 hr, ksi	NA	37	12	4
Stress Corrosion (transverse)(g)	No Cracks			
80% TYS, 1000 hr maximum				
Coefficient of Thermal Expansion				
12.9×10^{-6} in./in./F (70 to 212 F)				
Density				
0.099 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6L and 6T tests.

(e) Specimens were slow-bend type 1-inch thick x 2-inches wide with a span of 8 inches. K_{Ic} values are valid by existing ASTM criteria.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl

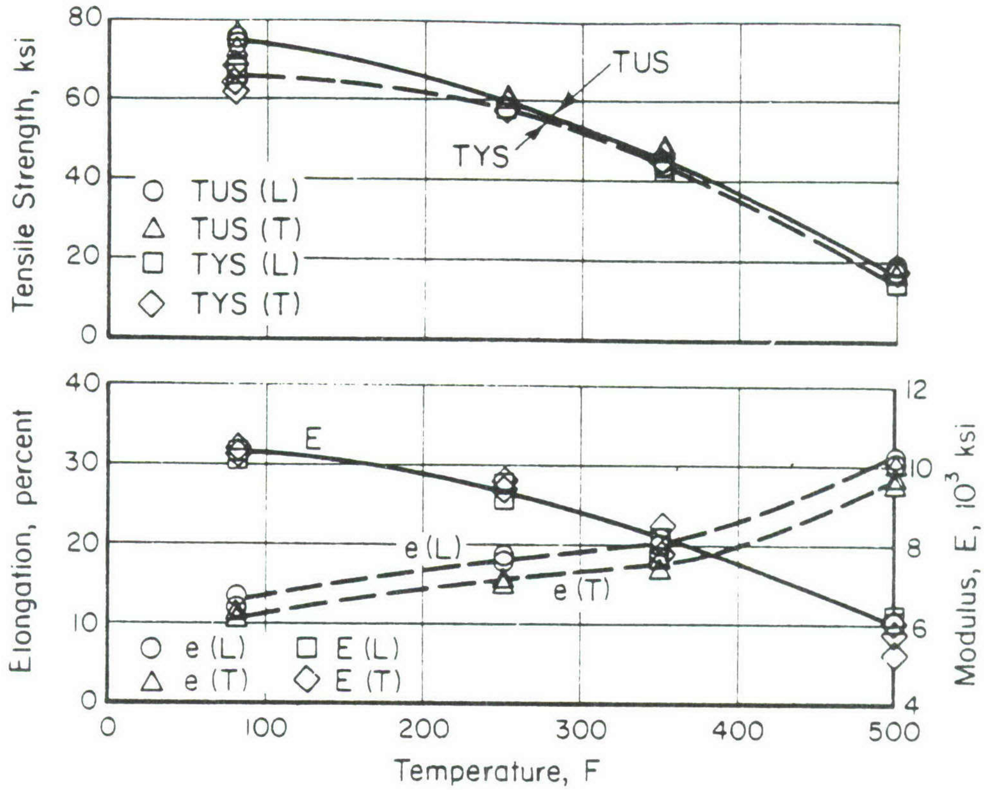


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T7351 ALUMINUM ALLOY PLATE

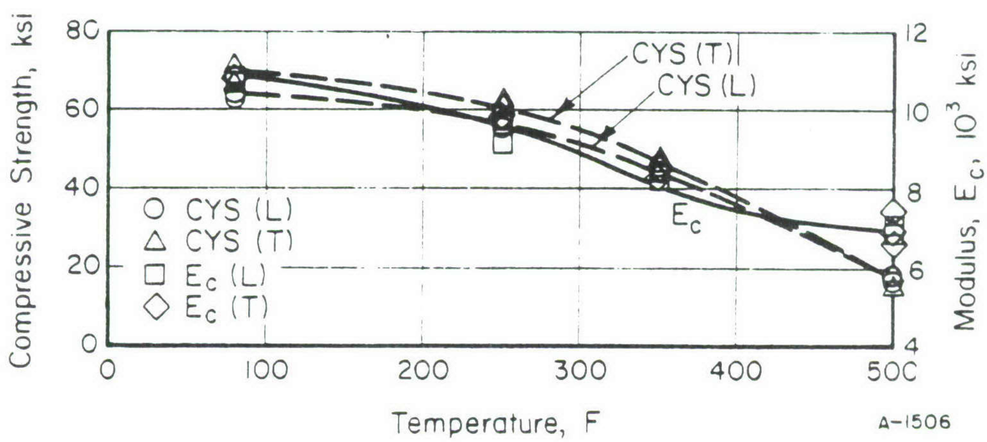


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7049-T7351 ALUMINUM ALLOY PLATE

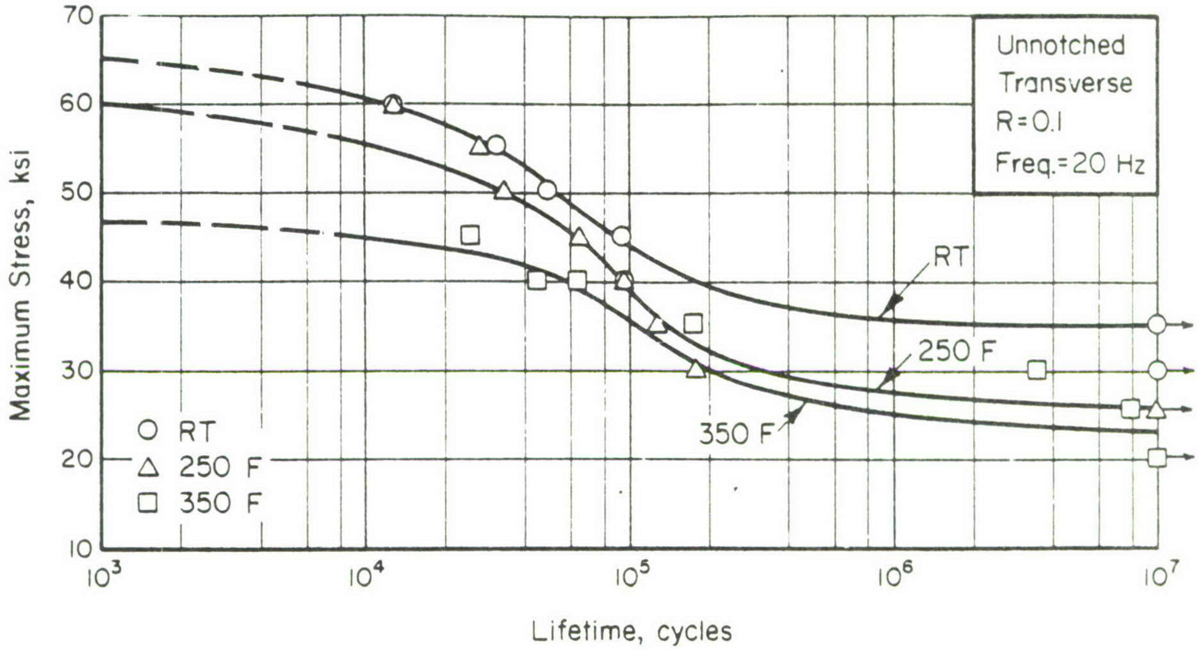


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7049-T7351 ALUMINUM ALLOY PLATE

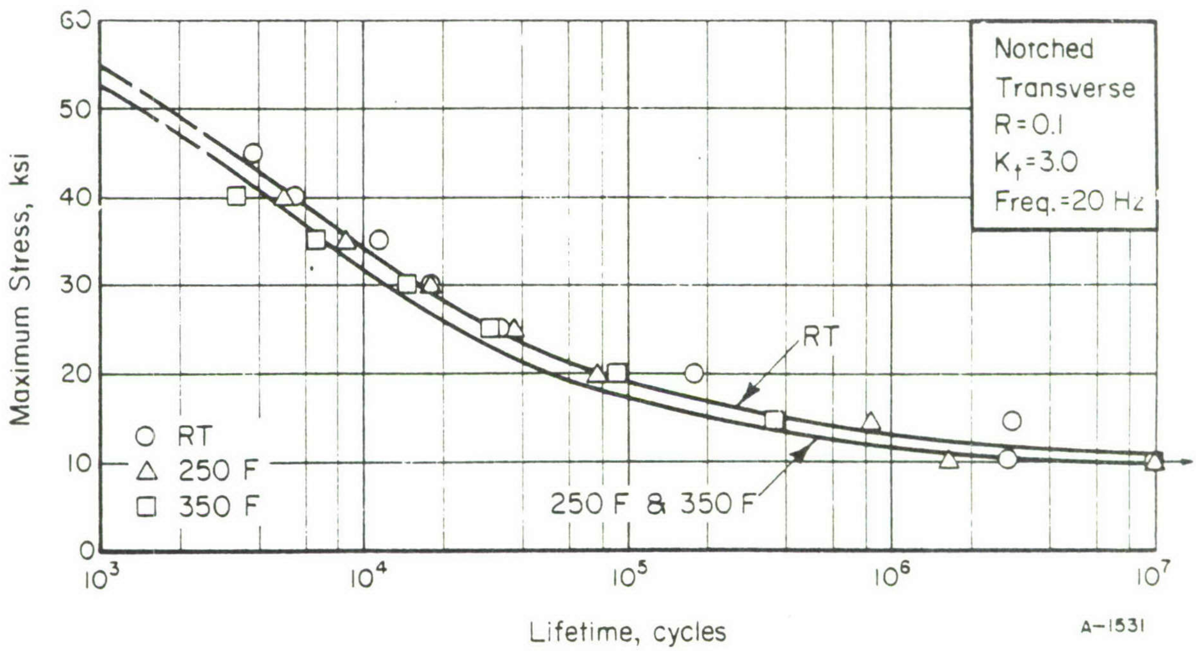


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7049-T7351 ALUMINUM ALLOY PLATE

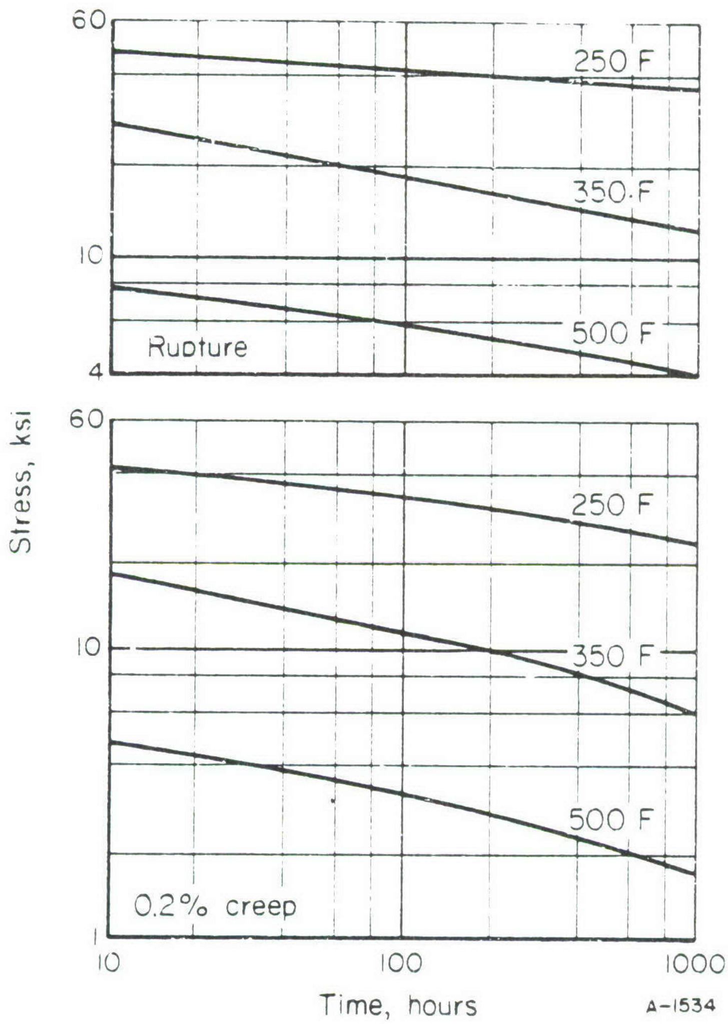


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7049-T7351 ALUMINUM ALLOY PLATE (TRANSVERSE)

Inconel 617 Alloy

Material Description

Inconel Alloy 617 is a solid-solution, nickel-chromium-cobalt-molybdenum alloy with an exceptional combination of high-temperature strength and oxidation resistance. It has excellent resistance to a wide range of corrosive environments, and is readily formed and welded by conventional techniques.

The high nickel and chromium contents make the alloy resistant to a variety of both reducing and oxidizing media. The aluminum, in conjunction with the chromium, provides oxidation resistance at high temperatures. Solid-solution strengthening is provided by the cobalt and molybdenum.

The combination of high strength and oxidation resistance at elevated temperatures makes this alloy an attractive material for gas-turbine aircraft engines and other applications involving exposure to extreme temperatures.

The material used for this evaluation was 0.047-inch-thick sheet from Heat XX00A7US with the following composition:

Chemical Composition	Percent
Chromium	22.0
Cobalt	12.5
Molybdenum	9.0
Aluminum	1.0
Carbon	0.07
Nickel	54.0

Processing and Heat Treating

Specimens were tested in the as-received cold-rolled and annealed condition.

INCONEL ALLOY 617 DATA[(a)]

Thickness: 0.047-inch nominal
Condition: Cold-rolled and annealed

Properties	Temperature, F RT	800	1200	1600
Tension				
TUS (longitudinal), ksi	122.4	103.3	83.9	24.6
TUS (transverse), ksi	123.6	105.7	96.0	24.8
TYS (longitudinal), ksi	56.6	41.0	38.2	21.7
TYS (transverse), ksi	56.5	43.4	39.3	22.9
e (longitudinal), percent in 2-in.	55.5	50.0	43.3	46.0
e (transverse), percent in 2-in.	56.2	50.7	46.7	55.0
E (longitudinal), 10^3 ksi	27.0	23.6	23.1	17.0
E (transverse), 10^3 ksi	30.5	24.8	29.8	16.6
Compression				
CYS (longitudinal), ksi	61.9	48.9	41.0	30.9
CYS (transverse), ksi	61.5	49.9	41.6	31.6
E_c (longitudinal), 10^3 ksi	30.4	27.9	24.1	20.0
E_c (transverse), 10^3 ksi	33.7	29.7	27.5	24.2
Shear[(b)]				
SUS (longitudinal), ksi	106.6	U[(c)]	U	U
SUS (transverse), ksi	107.6	U	U	U
Bend (transverse)				
Minimum Radius	0T	U	U	U
Fracture Toughness				
K_c, T-L, ksi $\sqrt{in.}$	(d)	U	U	U
Axial Fatigue (transverse)[(e)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	115	95	88	U
10^5 cycles, ksi	93	67	67	U
10^7 cycles, ksi	67	60	60	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	80	65	61	U
10^5 cycles, ksi	52	46	43	U
10^7 cycles, ksi	32	36	31	U

Properties	RT	Temperature, F 800	1200	1600
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	(f)	43	7
0.2% plastic deformation, 1000 hr, ksi	NA	(f)	39	5
Rupture (transverse)				
Rupture, 100 hr, ksi	NA	103	62	14
Rupture, 1000 hr, ksi	NA	102	48	9
Stress Corrosion (transverse)(g)				
80% TYS, 1000 hr maximum	no cracks	U	U	U
Coefficient of Thermal Expansion				
7.6×10^{-6} in./in./F (RT to 800 F)				
8.0×10^{-6} in./in./F (RT to 1200 F)				
8.7×10^{-6} in./in./F (RT to 1600 F)				
Density				
0.302 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Sheet shear type specimen: average of four tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Specimens were 16-inches wide by 36-inches long with a saw-cut flaw in the center. Net stress at fracture was greater than the tensile yield strength of the material, therefore, the test was not valid for K_c.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) No appreciable deformation.

(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

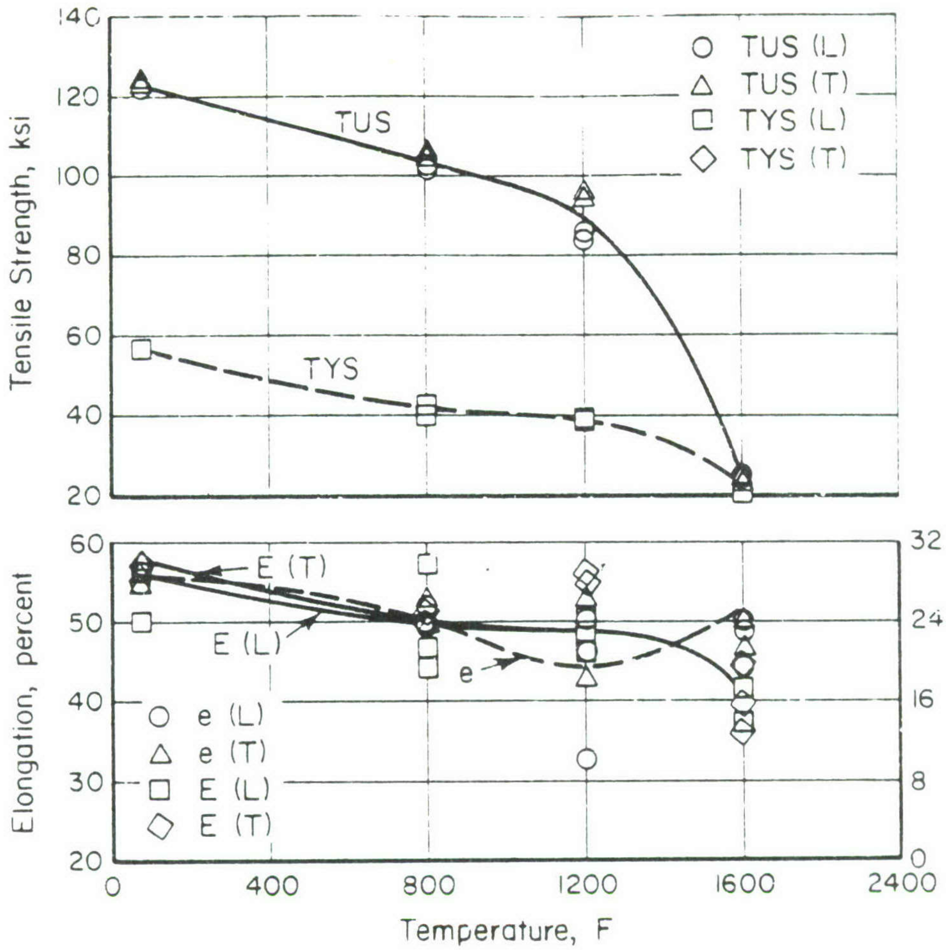


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED INCONEL ALLOY 617 SHEET

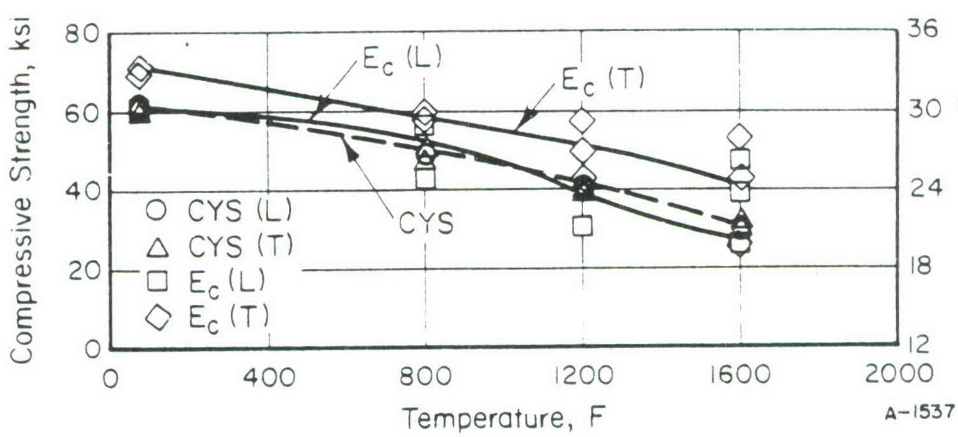


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ANNEALED INCONEL ALLOY 617 SHEET

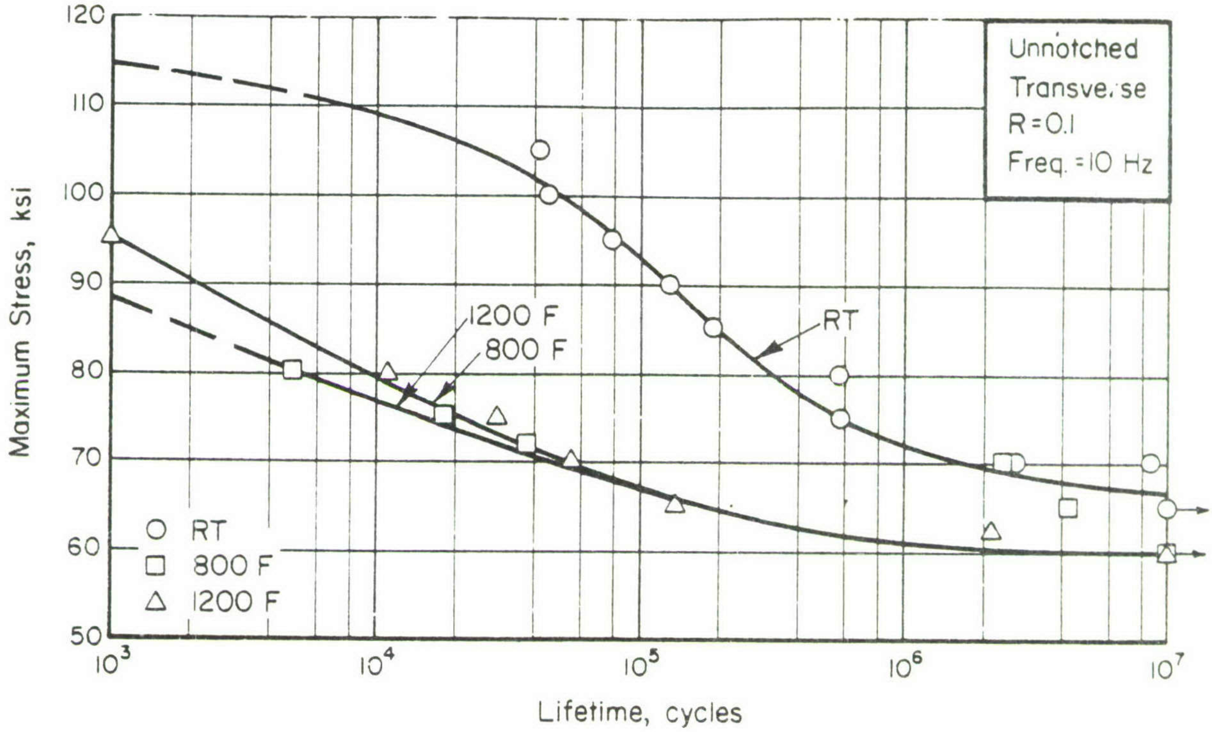


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ANNEALED INCONEL ALLOY 617 SHEET

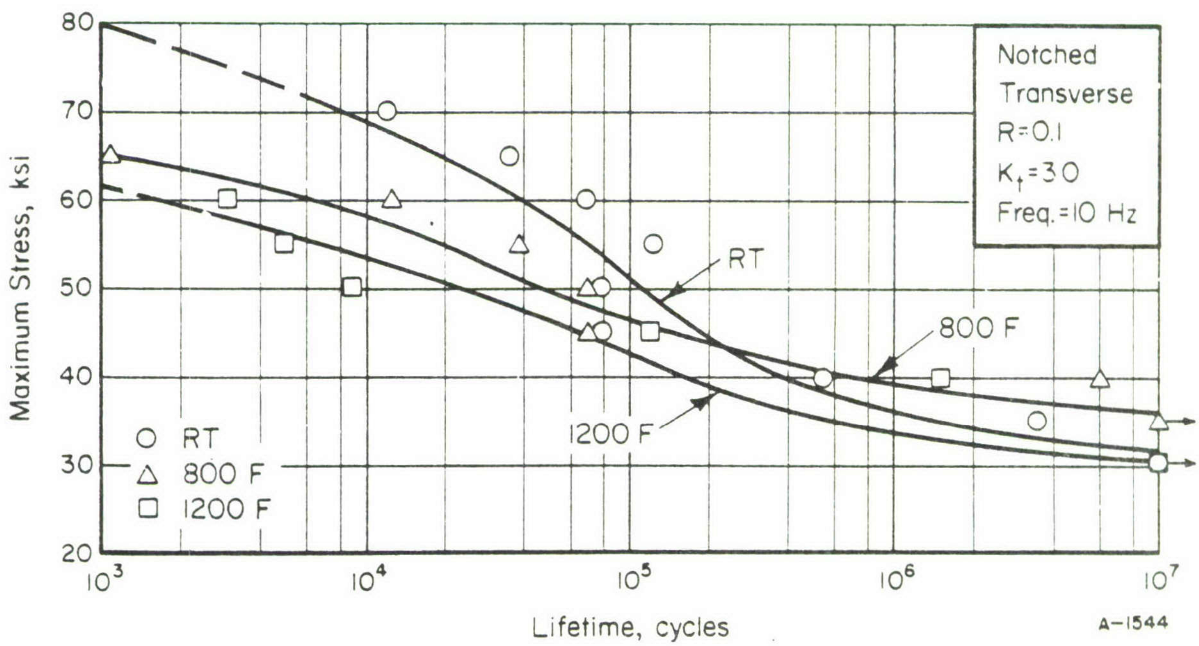


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t=3.0) ANNEALED INCONEL ALLOY 617 SHEET

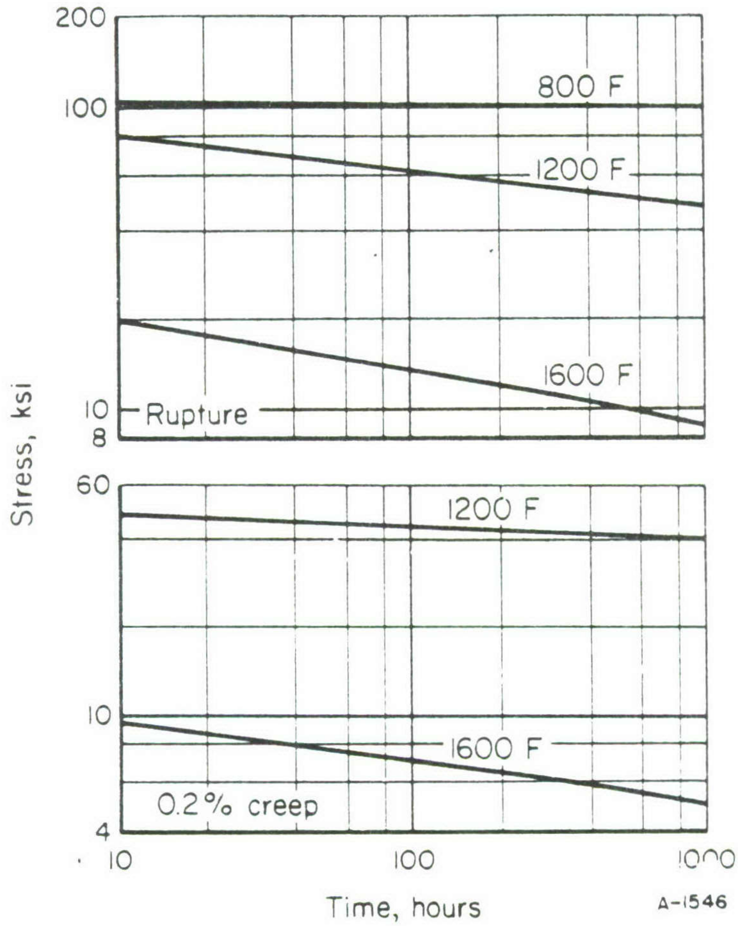


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR ANNEALED INCONEL ALLOY 617 SHEET

7475 Aluminum Alloy

Material Description

Alloy 7475 was developed by the Alcoa Laboratories for sheet and plate applications that require high strength and superior fracture toughness. This product was previously designated "Alcoa 467 Process X7475 Alloy". The 467 Process is a proprietary process developed to enhance the toughness of a high-purity 7075 type alloy. It is still used in the production of 7475 sheet and plate.

Alloy 7475 is available as bare and alclad sheet and plate. The material used in this evaluation was 2 inch thick bare plate produced within the following composition limits:

Composition	Percent
Silicon	0.10 max
Iron	0.12 max
Copper	1.2–1.9
Manganese	0.06 max
Magnesium	1.9–2.6
Chromium	0.18–0.25
Zinc	5.2–6.2
Titanium	0.6 max
Others	0.15 total
Aluminum	Balance

Processing and Heat Treating

The alloy was evaluated in the as-received -T7351 temper.

7475-T7351 ALLOY DATA[a]

Thickness: 2 inches

Properties	Temperature, F RT	250	350	500
Tension				
TUS (longitudinal), ksi	72.1	55.6	44.7	19.0
TUS (transverse), ksi	73.2	56.9	45.3	17.4
TYS (longitudinal), ksi	62.9	55.5	44.6	18.8
TYS (transverse), ksi	62.4	55.5	44.9	17.2
e (longitudinal), percent in 2 in.	18.3	17.3	20.5	35.5
e (transverse), percent in 2 in.	15.2	17.0	28.2	44.8
RA (longitudinal), percent	47.8	60.5	71.6	90.7
RA (transverse), percent	35.3	52.2	69.8	92.5
E (longitudinal), 10^3 ksi	10.2	9.0	7.8	7.1
E (transverse), 10^3 ksi	9.8	9.6	7.8	6.8
Compression				
CYS (longitudinal), ksi	61.0	54.9	46.4	18.5
CYS (transverse), ksi	65.5	57.6	48.4	18.9
E_c (longitudinal), 10^3 ksi	10.6	9.4	8.9	7.8
E_c (transverse), 10^3 ksi	10.5	9.9	9.6	7.7
Shear[b]				
SUS (longitudinal), ksi	45.7	U[c]	U	U
SUS (transverse), ksi	45.0	U	U	U
Impact[d]				
V-notch Charpy, ft/lb				
(longitudinal)	17.1	U	U	U
(transverse)	5.9	U	U	U
Fracture Toughness				
K_{Ic}, ksi $\sqrt{in.}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	63	55	45	U
10^5 cycles, ksi	53	48	41	U
10^7 cycles, ksi	48	37	27	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	52	50	45	U
10^5 cycles, ksi	24	20	17	U
10^7 cycles, ksi	13	11	10	U

Properties	Temperature, F RT	250	350	500
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	38	17	4
0.2% plastic deformation, 1000 hr, ksi	NA	29	10	2.5
Rupture (transverse)				
Rupture, 100 hr, ksi	NA	46	22	7
Rupture, 1000 hr, ksi	NA	41	15	5
Stress Corrosion (transverse)(g)				
80% TYS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion				
12.9×10^{-6} in./in./F (68 – 212 F)				
Density				
0.101 $lb/in.^3$				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Pin-shear tests. Average of four tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests in each direction.

(e) Specimens were slow-bend type 1-inch thick × 2-inches wide with an 8-inch span. Average K_Q obtained was 59.8 for L-T specimens and 55.3 for T-L specimens. These values are considered indicative of the material toughness, but do not meet the rigorous size standard of ASTM E399-72 and, therefore, are not valid K_{Ic} values.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3½% NaCl.

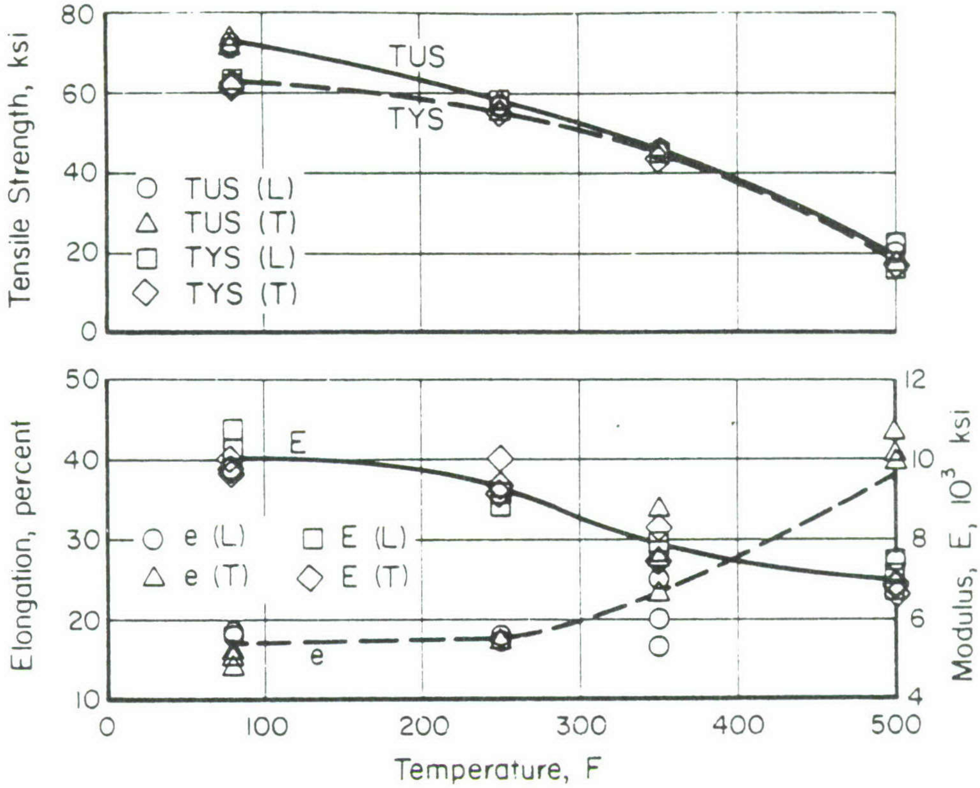


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7475-T7351 ALLOY PLATE

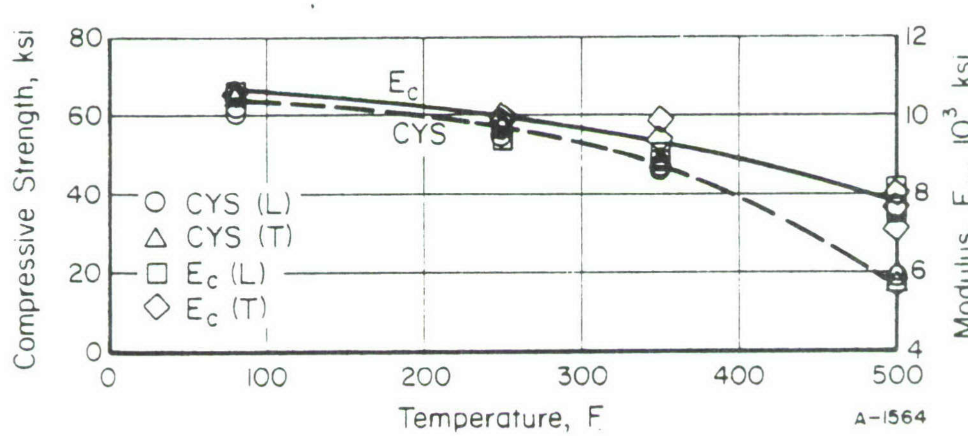


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7475-T7351 ALLOY PLATE

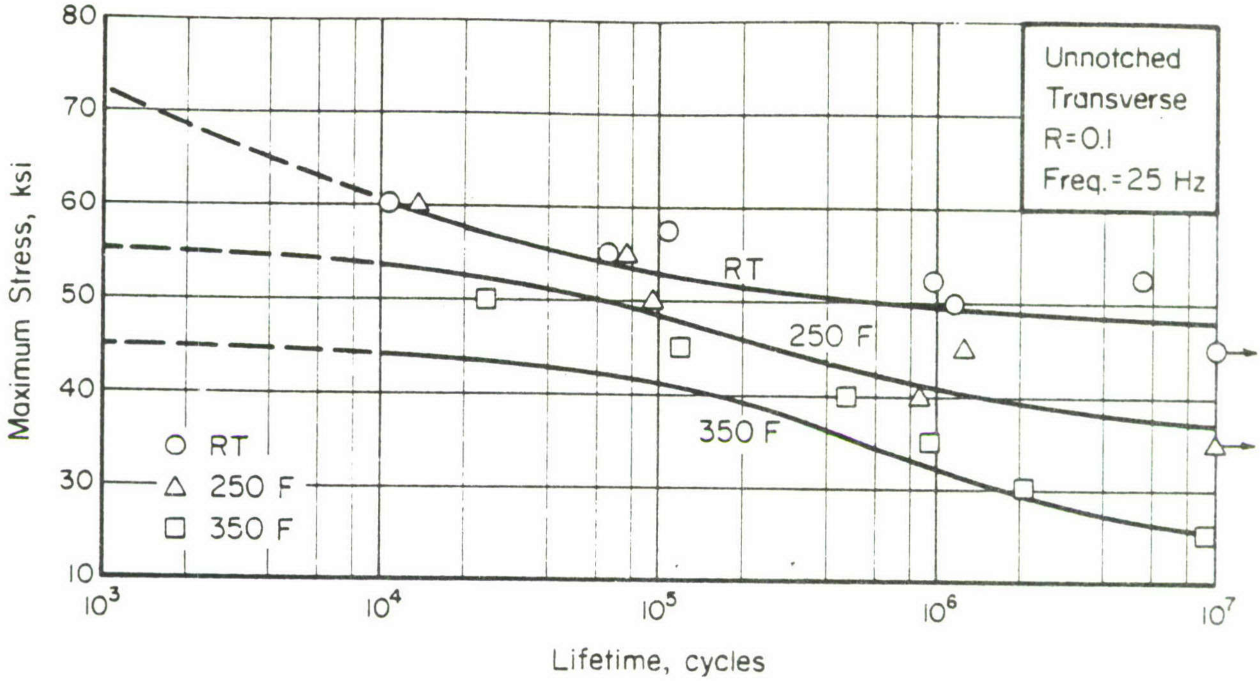


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7475-T7351 ALLOY PLATE

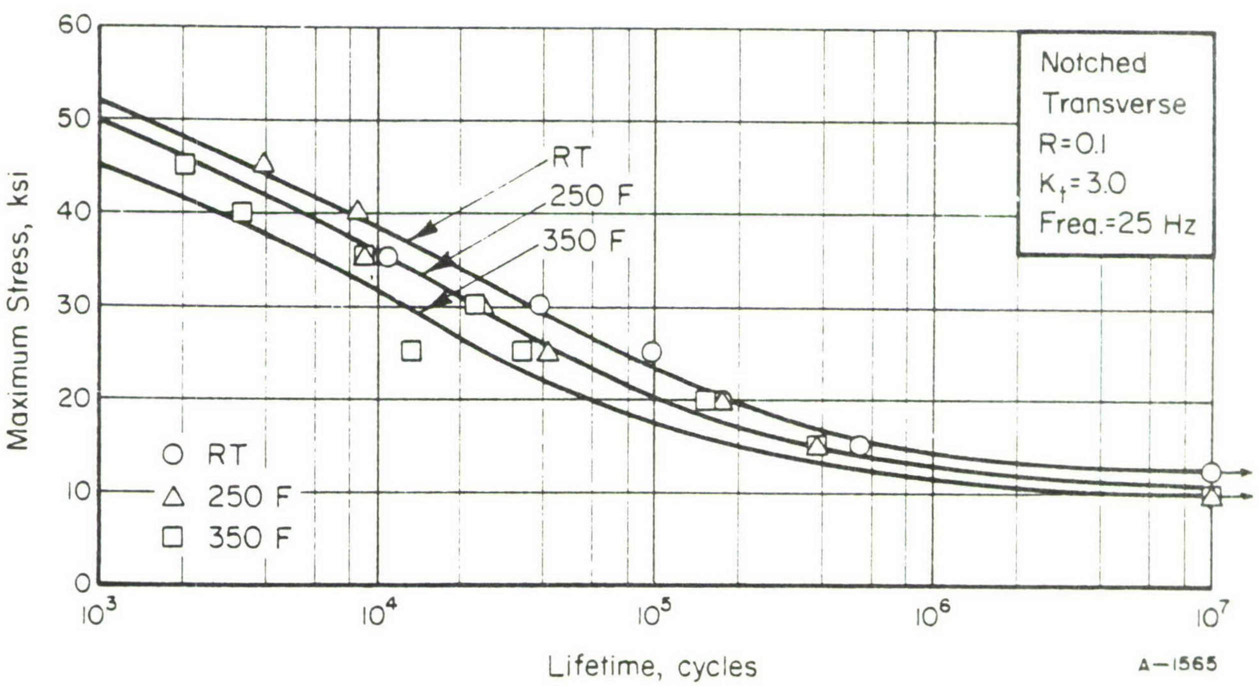


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7475-T7351 ALLOY PLATE

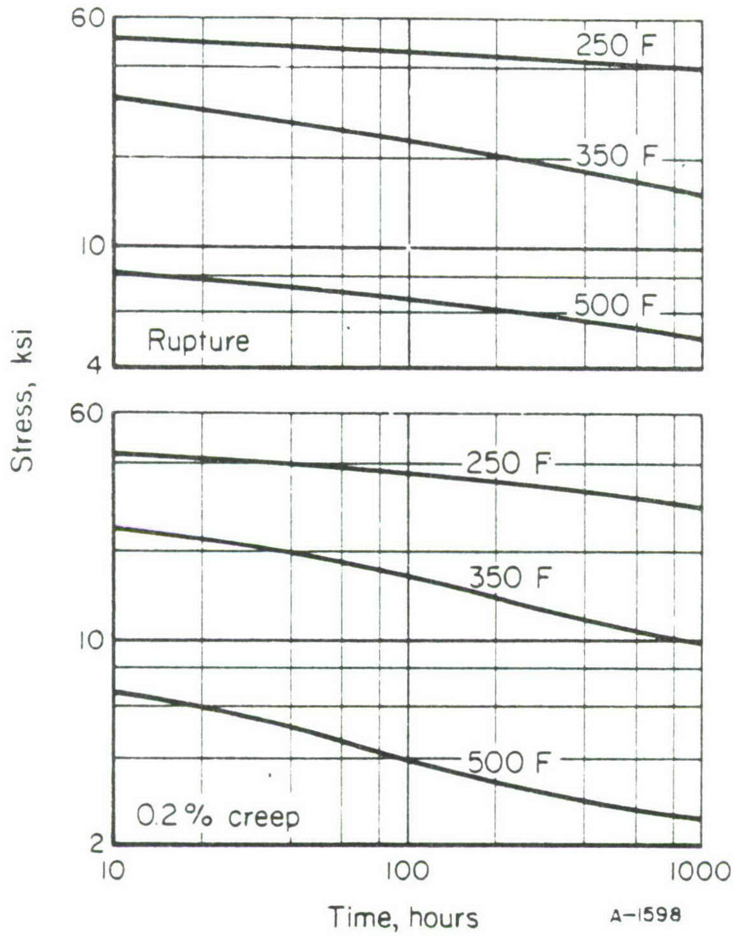


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7475-T7351 ALLOY PLATE (TRANSVERSE)

2419 Aluminum Alloy

Material Description

Alloy 2419 is a recent development of the Aluminum Company of America. It is essentially a 2219 alloy with more closely controlled composition. Mechanical properties are the same as 2219 with improved fracture toughness. The alloy is readily weldable and is useful for applications at a wide range of temperatures from -452 F to about 600 F.

Composition limits for 2419 are as shown:

Chemical Composition	Percent
Silicon	0.15 max.
Iron	0.18 max.
Copper	5.8 to 6.8
Manganese	0.20 to 0.40
Magnesium	0.02 max.
Zinc	0.10 max.
Titanium	0.02 to 0.10
Others	each 0.05, total 0.15
Aluminum	Balance

The material used for this evaluation was a 2-inch-thick plate from Alcoa lot number 270-841.

Processing and Heat Treatment

The alloy was evaluated in the overaged and stress-relieved -T851 temper.

2419-T851 Alloy Data

Condition: -T851
Thickness: 2-inch plate

Properties	RT	250	350	500
	Temperature, F			
Tension				
TUS (longitudinal), ksi	66.7	55.4	45.5	22.2
TUS (transverse), ksi	66.4	54.9	44.5	23.1
TYS (longitudinal), ksi	52.4	46.8	41.4	20.9
TYS (transverse), ksi	52.1	45.6	39.7	21.7
e (longitudinal), percent in 2 in.	11.0	15.0	14.5	18.0
e (transverse), percent in 2 in.	10.7	13.2	14.8	18.0
RA (longitudinal), percent	23.6	37.9	48.4	53.2
RA (transverse), percent	18.1	33.9	46.2	51.6
E (longitudinal), 10^3 ksi	10.4	10.4	9.1	7.4
E (transverse), 10^3 ksi	10.8	9.5	9.5	9.1
Compression				
CYS (longitudinal), ksi	53.3	47.8	42.2	25.5
CYS (transverse), ksi	51.7	46.9	41.7	25.5
E_c (longitudinal), 10^3 ksi	10.8	10.5	10.0	9.3
E_c (transverse), 10^3 ksi	10.7	10.4	9.8	9.0
Shear				
SUS (longitudinal), ksi	39.4	U	U	U
SUS (transverse), ksi	39.5	U	U	U
Impact				
V-notch Charpy, ft-lb				
(longitudinal)	5.5	U	U	U
(transverse)	4.3	U	U	U
Fracture Toughness				
K_{Ic} (L-T), ksi$\sqrt{\text{in.}}$	35.3	U	U	U
K_{Ic} (T-L), ksi$\sqrt{\text{in.}}$	30.2	U	U	U
Axial Fatigue (transverse)$^{(f)}$				
Unnotched, R = 0.1				
10^3 cycles, ksi	66	55	45	U
10^5 cycles, ksi	42	42	39	U
10^7 cycles, ksi	36	30	26	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	50	48	48	U
10^5 cycles, ksi	19	17	17	U
10^7 cycles, ksi	11	10	10	U

2419-T851 Alloy Data (Continued)

Properties	RT	Temperature, F 250	350	500
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	36	23	9.4
0.2% plastic deformation, 1000 hr, ksi	NA	32	18	6.2
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	44	31	14
Rupture, 1000 hr, ksi	NA	41	26	9.4
Stress Corrosion (transverse)(g)				
80% TYS, 1000 hr maximum	No cracks			
Coefficient of Thermal Expansion				
12.4×10^{-6} in./in./F (70 to 212 F)				
Density				
0.102 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests in each direction.

(e) Specimens were slow-bend type 1-inch thick by 2-inches wide with a span of 8 inches. K_{Ic} values are valid by existing ASTM criteria.

(f) "R" represents the albebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3½% NaCl.

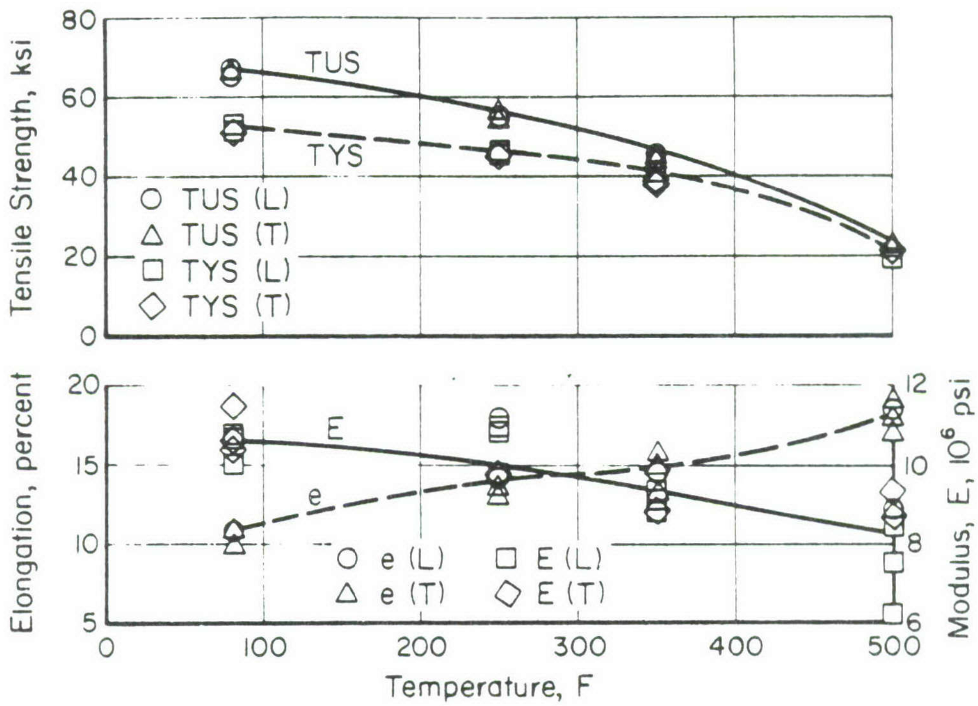


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 2419-T851 ALLOY PLATE

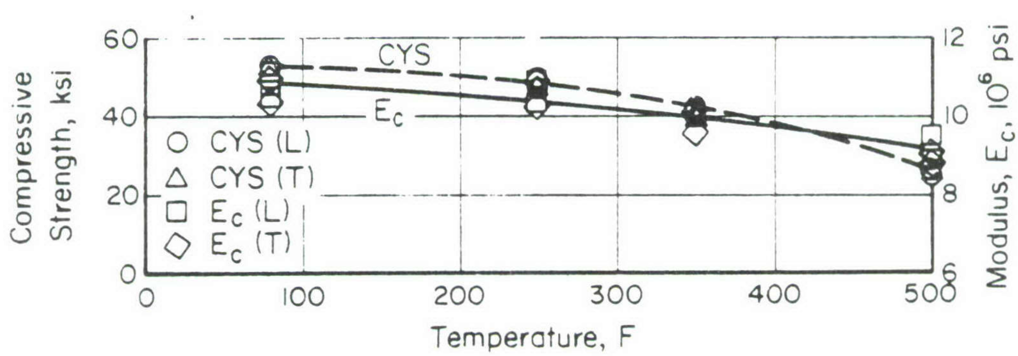


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 2419-T851 ALLOY PLATE

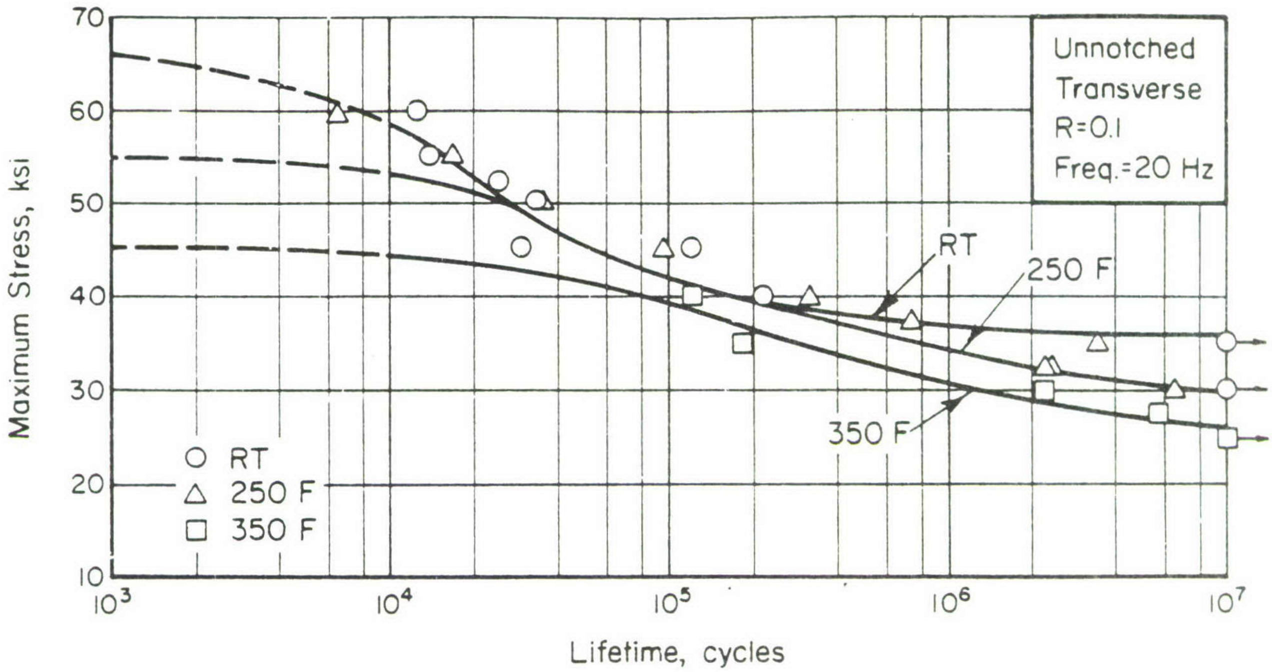


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 2419-T851 ALUMINUM ALLOY PLATE

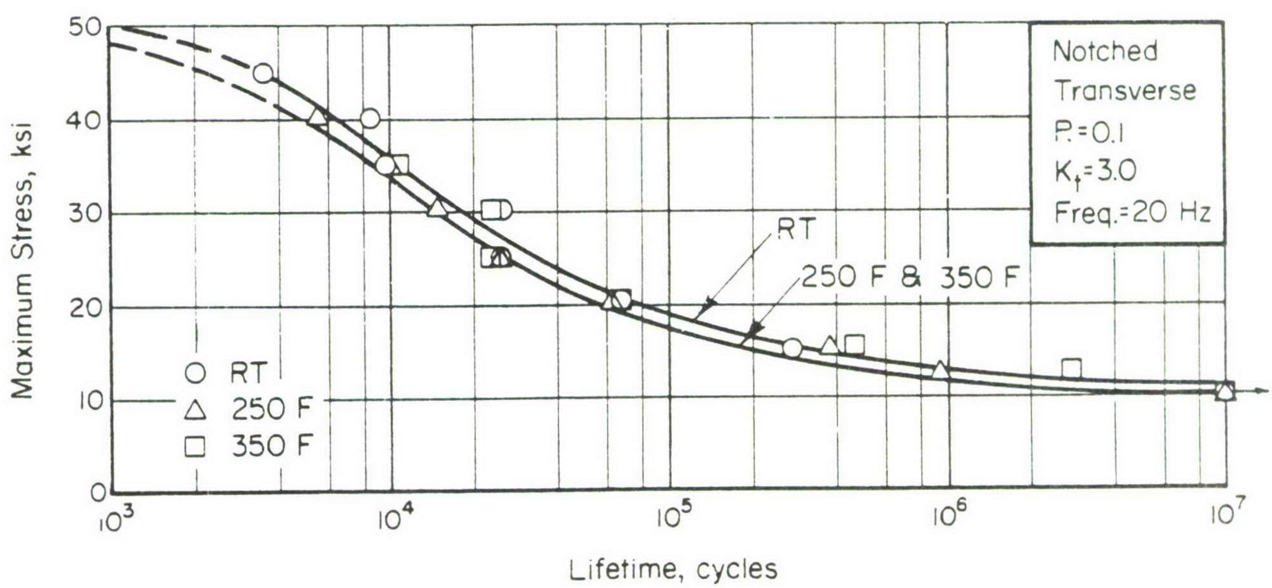


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 2419-T851 ALUMINUM ALLOY PLATE

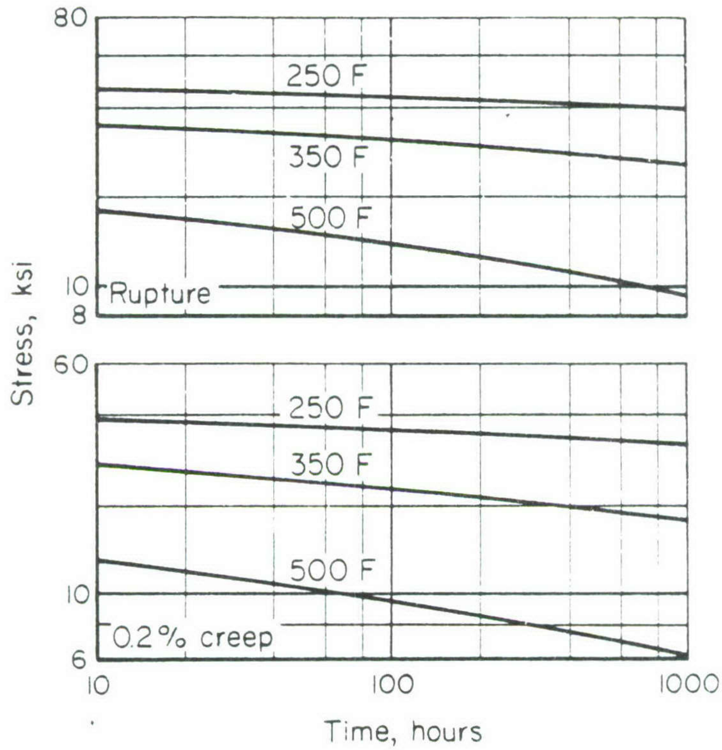


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 2419-T851 ALUMINUM ALLOY PLATE

Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy

Material Description

This alpha-beta alloy, designed for deep hardenability, is a recent development of RMI Company. Preliminary information shows the material also to have low density, high modulus, high toughness, and good producibility. Strength retention to 800 F is good.

The material used for this evaluation was a 4-inch x 6-inch forged billet from RMI ingot number 890180 which had the following chemistry:

Element	Percent
Al	5.8
Sn	2.1
Zr	1.8
Mo	2.0
Cr	1.9
Si	0.21
Fe	0.06
C	0.02
V	0.02
Ti	Balance

Additional information on this alloy is available from work performed by RMI Company under Air Force Contract F33615-72-C-1152.

Processing and Heat Treating

The billet was heat-treated to the duplex-annealed condition by RMI Company using the following procedure: 1745 F, 1 hour, air cool to 1560 F and water quench; plus 1000 F for 8 hours and air cool. Specimens received no further heat-treatment before testing.

Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY DATA[(a)]

Condition: duplex annealed
Thickness: 4 inch x 6 inch forged billet

Properties	Temperature, F RT	400	600	800
Tension				
TUS (longitudinal), ksi	158.4	136.3	137.3	139.8
TUS (transverse), ksi	166.0	145.5	132.1	132.9
TYS (longitudinal), ksi	143.9	111.0	102.5	102.0
TYS (transverse), ksi	150.4	117.4	100.6	98.8
e (longitudinal), percent in 2 in.	15.3	16.3	15.3	16.5
e (transverse), percent in 2 in.	13.7	14.0	16.0	18.3
RA (longitudinal), percent	36.0	47.4	36.0	47.2
RA (transverse), percent	36.7	48.1	40.3	48.8
E (longitudinal), 10^3 ksi	15.6	14.7	14.5	13.4
E (transverse), 10^3 ksi	15.8	13.9	14.8	13.4
Compression				
CYS (longitudinal), ksi	149.4	116.2	106.4	97.9
CYS (transverse), ksi	154.6	122.2	107.5	102.1
E_c (longitudinal), 10^3 ksi	16.1	14.7	14.3	13.2
E_c (transverse), 10^3 ksi	16.1	15.3	14.8	13.4
Shear[(b)]				
SUS (longitudinal), ksi	102.8	U[(c)]	U	U
SUS (transverse), ksi	105.1	U	U	U
Impact[(d)]				
V-notch Charpy, ft. lbs.				
(longitudinal)	14.9	U	U	U
(transverse)	14.9	U	U	U
Fracture Toughness[(e)]				
K_{Ic}, L-T, edge, ksi$\sqrt{in.}$	45.1	U	U	U
K_{Ic}, L-T, center, ksi$\sqrt{in.}$	51.8	U	U	U
K_{Ic}, ST-L, center, ksi$\sqrt{in.}$	62.0	U	U	U
Axial Fatigue (transverse)[(f)]				
Unnotched, R=0.1				
10^3 cycles, ksi	164	144	134	U
10^5 cycles, ksi	130	112	106	U
10^7 cycles, ksi	76	76	76	U
Notched, K_t=3.0, R=0.1				
10^3 cycles, ksi	110	100	92	U
10^5 cycles, ksi	50	46	46	U
10^7 cycles, ksi	40	40	40	U

Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY DATA

(Continued)

Properties	Temperature, F			
	RT	400	600	800
Creep (transverse)				
0.2% plastic deformation, 100 hr., ksi	NA	107	96	70
0.2% plastic deformation, 1000 hr., ksi	NA	102	70	44
Stress-Rupture (transverse)				
Rupture, 100 hr., ksi	NA	133.5	129	121
Rupture, 1000 hr., ksi	NA	133	128.5	118
Stress Corrosion (transverse)(g)	no cracks			
Coefficient of Thermal Expansion				
5.1×10^{-6} in./in./F (68 to 800 F)				
Density				
0.165 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable: NA, not applicable.

(d) Average of 6 tests in each direction.

(e) Values shown are from valid tests at RMI Company. Battelle tests were considered marginally valid and are not reported, even though they generally agreed with the RMI results.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R=S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

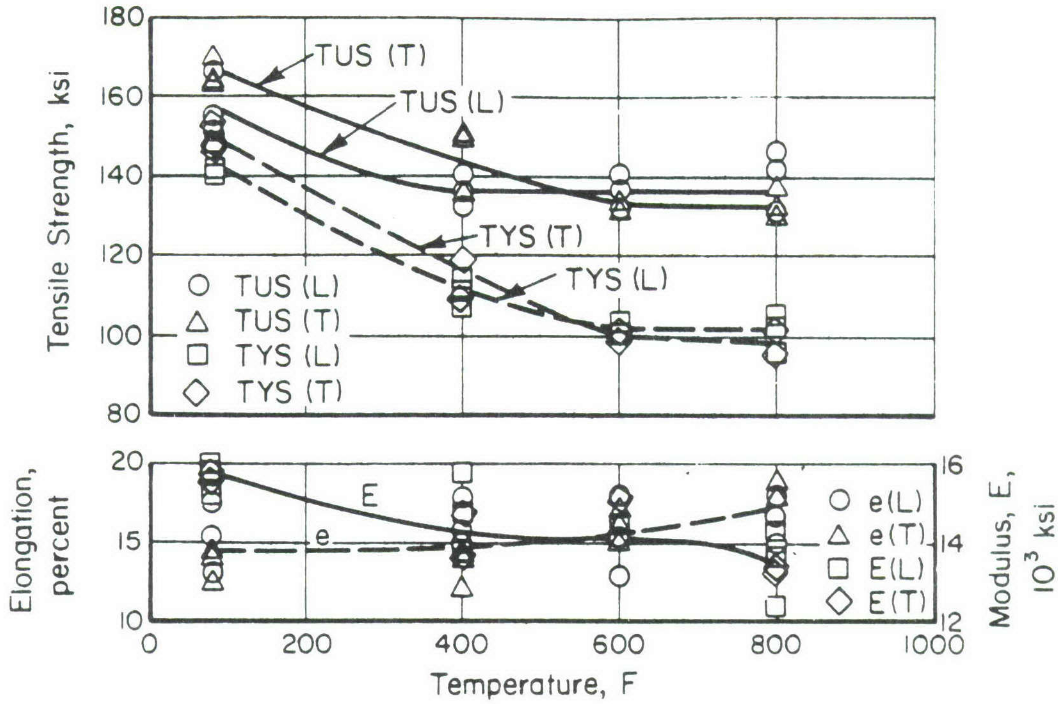


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF DUPLEX ANNEALED Ti-6Al-2Zr-2Sn-2Mo-2Cr FORGED BILLET

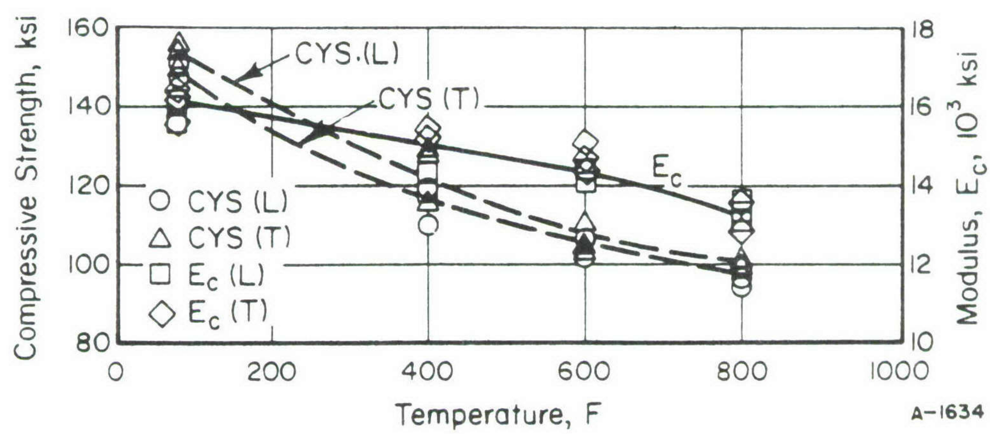


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF DUPLEX ANNEALED Ti-6Al-2Zr-2Sn-2Mo-2Cr FORGED BILLET

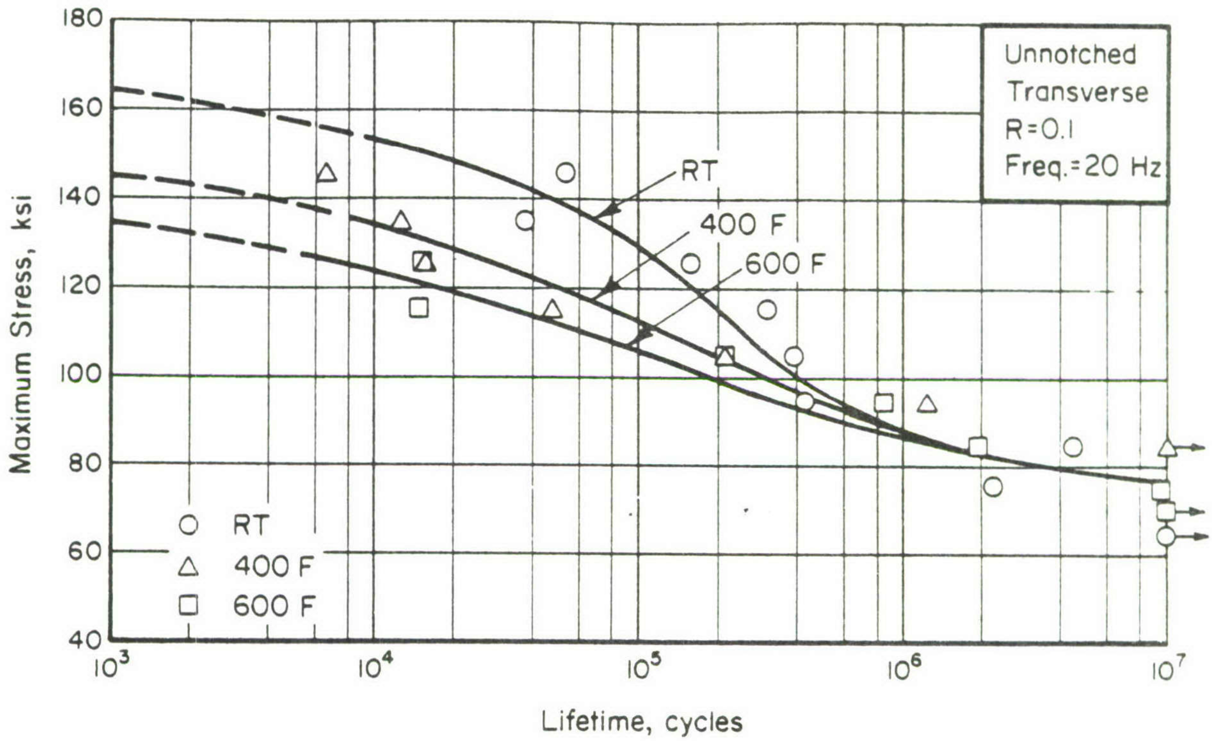


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED DUPLEX ANNEALED Ti-6Al-2Zr-2Sn-2Mo-2Cr FORGED BILLET

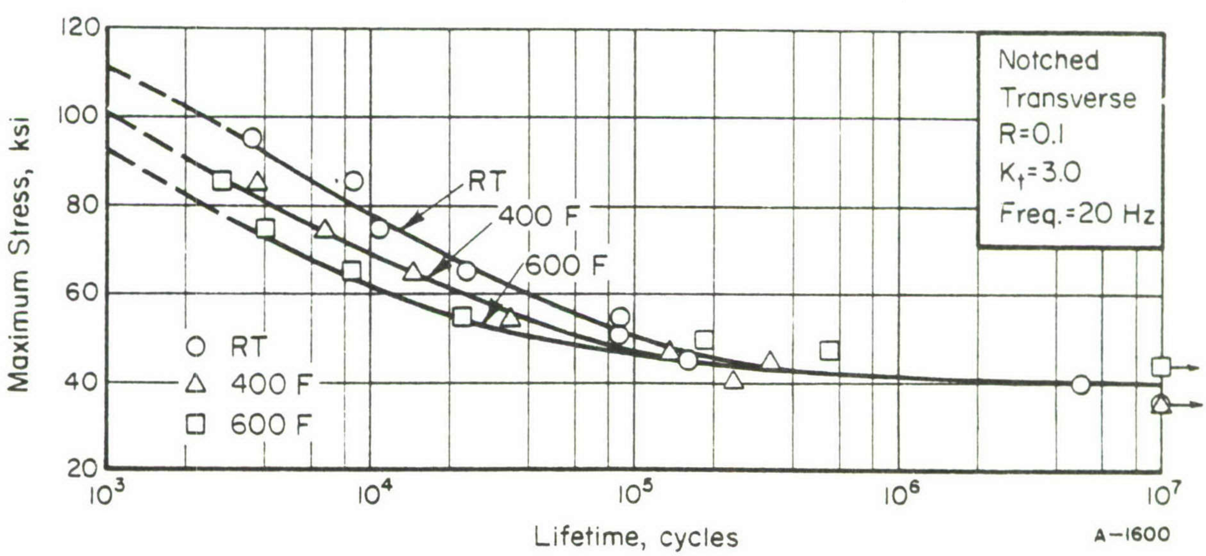


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) DUPLEX ANNEALED Ti-6Al-2Zr-2Sn-2Mo-2Cr FORGED BILLET

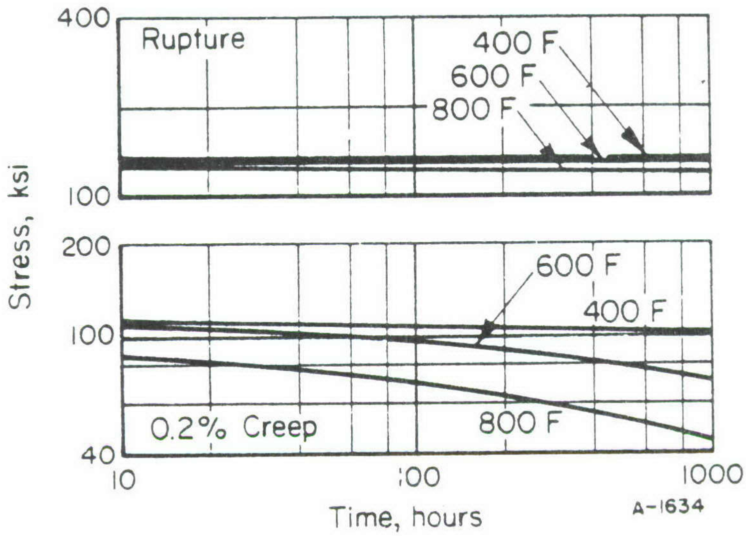


FIGURE 5. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Zr-2Sn-2Mo-2Cr FORGED BILLET (TRANSVERSE)

Ti-6Al-2Cb-1Ta-1Mo Alloy

Material Description

6Al-2Cb-1Ta-1Mo titanium alloy is a modification by RMI Company of the Ti-7Al-2Cb-1Ta composition. The modification was developed specifically for salt-water stress-corrosion resistance. The alloy is of medium strength and is forgeable and weldable. It is generally used in the annealed condition. Some increase in strength can be obtained by solution treating and aging, but at a sacrifice in ductility and toughness.

Ti-6Al-2Cb-1Ta-1Mo is available as billet, bar, plate, sheet, and wire. It is normally processed in the beta phase region.

The material evaluated was a 1½-inch-thick plate from RMI ingot number 294447 with the following composition:

Chemical Composition	Percent
Carbon	.02
Nitrogen	.006
Iron	.07
Aluminum	6.0
Columbium	1.9
Tantalum	.93
Molybdenum	.77
Oxygen	.080
Titanium	Balance

Processing and Heat Treating

The material was evaluated in the as-received, beta processed and annealed (1825 F, 1 hour, air cooled) condition.

Ti-6Al-2Cb-1Ta-1Mo Alloy Data[a]

Condition: Annealed
Thickness: 1½-inch plate

Properties	Temperature, F RT	400	600	800
Tension				
TUS (longitudinal), ksi	117.6	87.8	80.2	74.0
TUS (transverse), ksi	119.3	89.0	80.5	75.2
TYS (longitudinal), ksi	102.1	64.5	58.0	52.4
TYS (transverse), ksi	103.7	65.8	56.1	55.4
e (longitudinal), percent in 2 in.	18.3	18.3	19.6	19.7
e (transverse), percent in 2 in.	17.3	17.3	18.0	17.3
RA (longitudinal), percent	33.8	42.6	51.7	50.3
RA (transverse), percent	32.9	42.6	47.2	49.0
E (longitudinal), 10^3 ksi	17.0	16.0	14.0	12.8
E (transverse), 10^3 ksi	17.0	17.4	14.8	14.4
Compression				
CYS (longitudinal), ksi	108.3	74.2	60.8	55.2
CYS (transverse), ksi	111.9	77.4	63.2	58.3
E_c (longitudinal), 10^3 ksi	17.6	15.9	15.0	13.7
E_c (transverse), 10^3 ksi	17.5	15.6	14.9	13.9
Shear[b]				
SUS (longitudinal), ksi	83.7	U[c]	U	U
SUS (transverse), ksi	83.8	U	U	U
Impact[d]				
V-notch Charpy, ft/lb				
(longitudinal)	38.5	U	U	U
(transverse)	33.8	U	U	U
Fracture Toughness				
K_{Ic}, ksi $\sqrt{in.}$	(e)	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	115	90	80	U
10^5 cycles, ksi	97	78	74	U
10^7 cycles, ksi	68	57	54	U

Ti-6Al-2Cb-1Ta-1Mo Alloy Data (continued)

Properties	Temperature, F			
	RT	400	600	800
Notched, K_t = 3.0, R = 0.1				
10^4 cycles, ksi	90	83	80	U
10^5 cycles, ksi	49	45	40	U
10^7 cycles, ksi	28	26	25	U
<u>Creep (transverse)</u>				
0.2% plastic deformation, 100 hr, ksi	NA[c]	67	73	61
0.2% plastic deformation, 1000 hr, ksi	NA	66	72	52
<u>Stress Rupture (transverse)</u>				
Rupture, 100 hr, ksi	NA	88	81	73
Rupture, 1000 hr, ksi	NA	87	80	72
<u>Stress Corrosion</u>[g]				
80% TYS, 1000 hr maximum	No cracks			
<u>Coefficient of Thermal Expansion</u>				
5.2×10^{-6} in./in./F(RT to 1200 F)				
<u>Density</u>				
0.162 lb/in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of four tests.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests in each direction.

(e) Specimens were slow-bend type 1-inch thick x 2-inches wide with a span of 8 inches. Tests did not meet the size standard of ASTM E399-72. From this specification, the specimen strength ratios (R_{sb}) were calculated. These averaged 2.18 for L-T specimens and 1.82 for T-L specimens.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room temperature three-point bend test. Alternate immersion in 3½% NaCl.

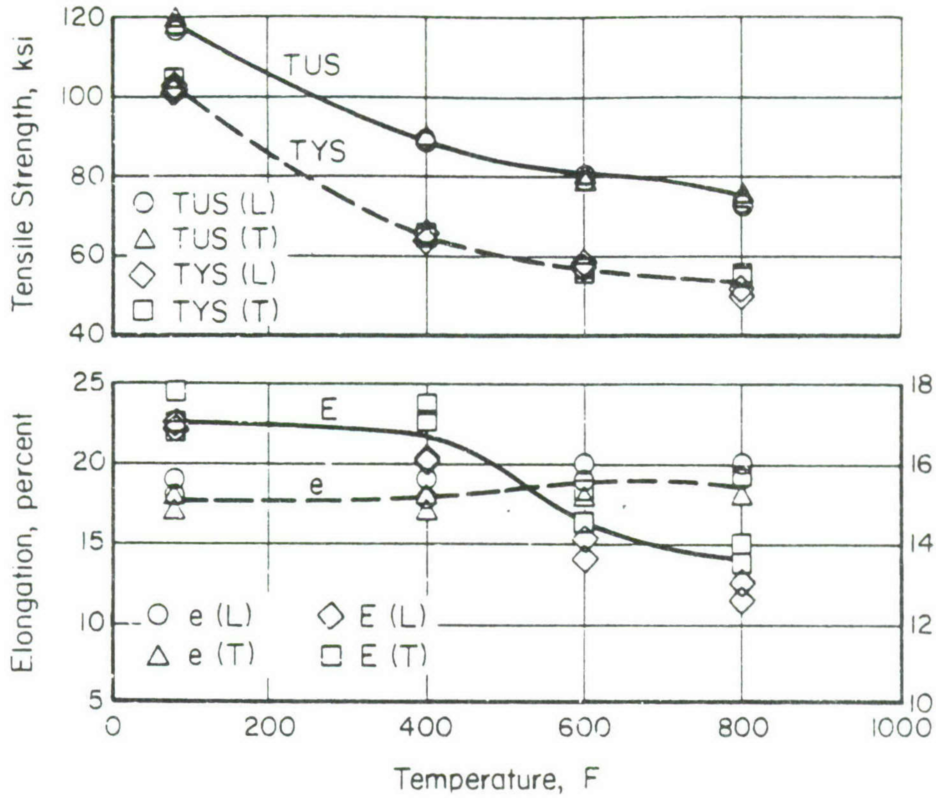


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED Ti-6Al-2Cb-1Ta-1Mo ALLOY PLATE

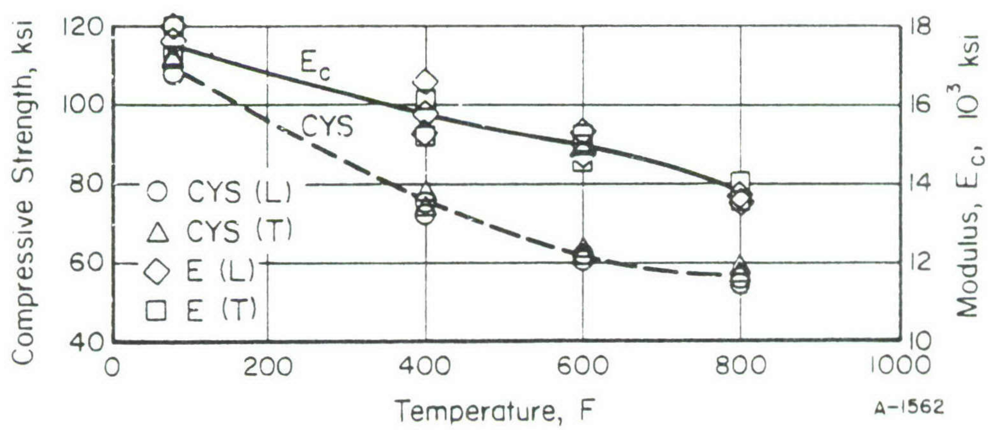


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ANNEALED Ti-6Al-2Cb-1Ta-1Mo ALLOY PLATE

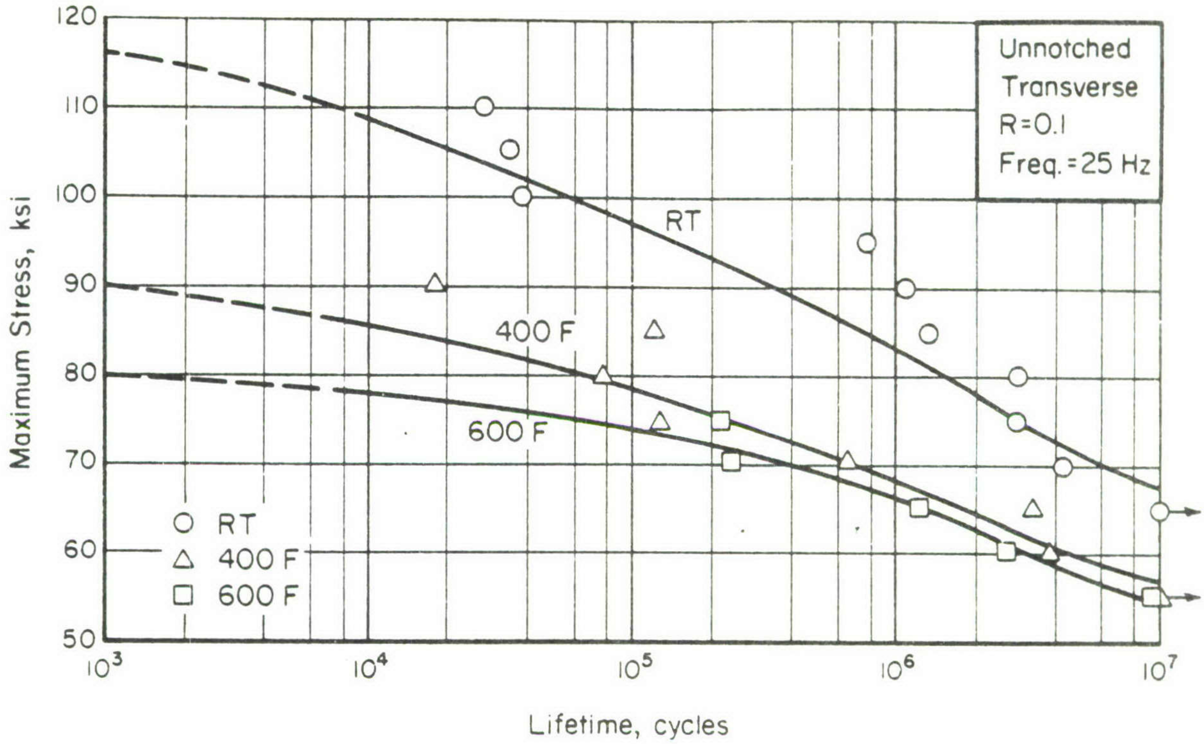


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ANNEALED Ti-6Al-2Cb-1Ta-1Mo ALLOY PLATE

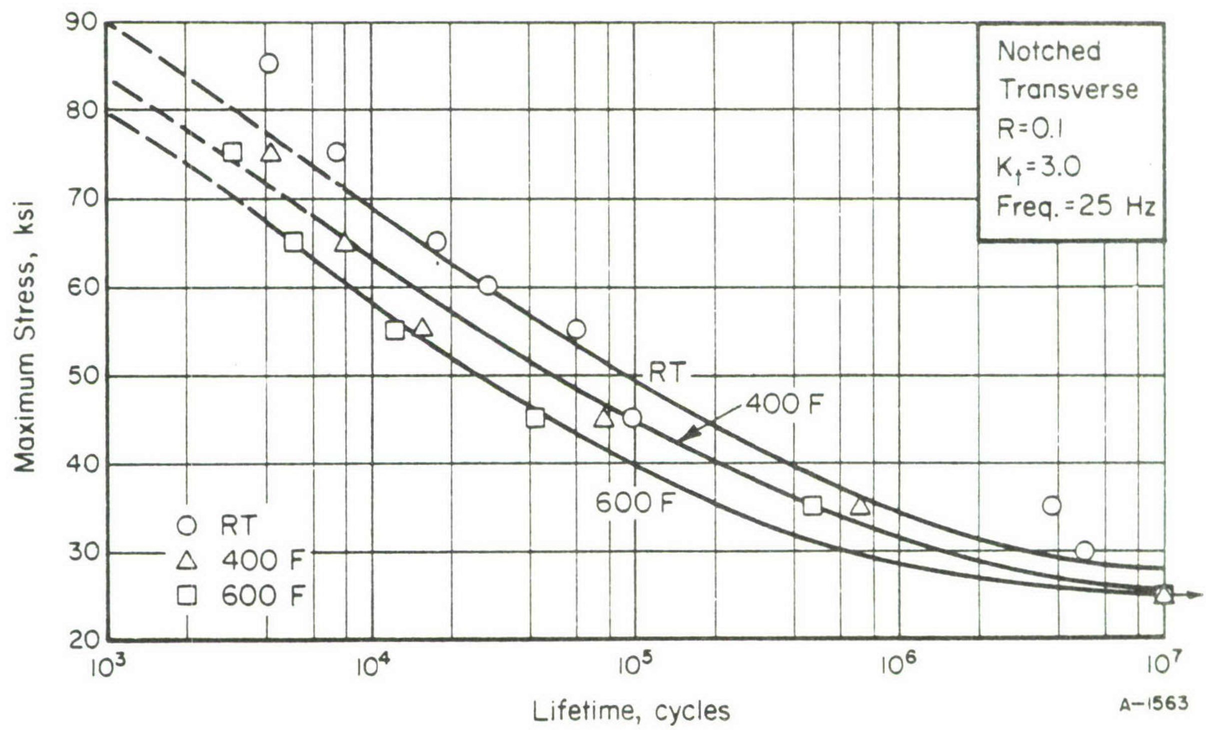


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) ANNEALED Ti-6Al-2Cb-1Ta-1Mo ALLOY PLATE

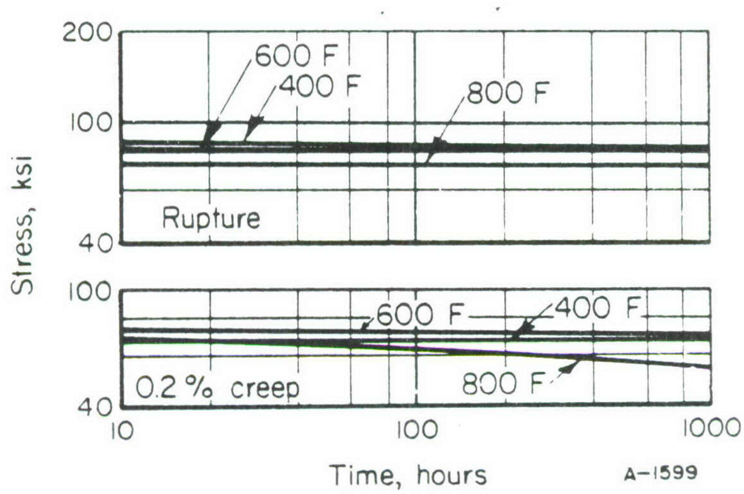


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR ANNEALED Ti-6Al-2Cb-1Ta-1Mo ALLOY PLATE

Ti-6Al-4V Alloy

Material Description

Ti-6Al-4V is one of the most used titanium alloy and thus needs no descriptive words. It is used in great quantities and in various product forms for aerospace and other applications. The 0.57-inch-thick plate used for this evaluation was GFM from material produced for Boeing to their low oxygen specification.

Processing and Heat Treating

The material was tested in the as-received, beta-annealed condition.

Ti-6Al-4V ALLOY DATA[a]

Condition: Beta annealed
Thickness: 0.57 plate

Properties	Temperature, F RT	400	600	800
Tension				
TUS (longitudinal), ksi	135.8	103.3	92.5	83.0
TUS (transverse), ksi	136.0	103.7	92.7	82.5
TYS (longitudinal), ksi	127.7	86.1	72.1	65.6
TYS (transverse), ksi	126.7	85.6	71.5	64.1
e (longitudinal), percent in 2 in.	12.2	16.0	15.0	20.7
e (transverse), percent in 2 in.	12.0	15.7	14.3	18.3
RA (longitudinal), percent	20.9	34.4	35.1	48.8
RA (transverse), percent	27.4	32.2	34.3	45.0
E (longitudinal), 10^3 ksi	17.5	16.1	15.9	13.2
E (transverse), 10^3 ksi	16.9	16.5	15.3	13.9
Compression				
CYS (longitudinal), ksi	132.4	89.5	73.5	68.3
CYS (transverse), ksi	134.8	91.4	76.6	69.9
E_c (longitudinal), 10^3 ksi	17.1	15.8	14.8	14.0
E_c (transverse), 10^3 ksi	17.5	15.4	15.1	14.0
Shear[b]				
SUS (longitudinal), ksi	90.6	U[c]	U	U
SUS (transverse), ksi	89.9	U	U	U
Impact[d]				
V-notch Charpy, ft.lbs.				
(longitudinal)	23.6	U	U	U
(transverse)	23.2	U	U	U
Fracture Toughness	(e)			
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	126	102	92	U
10^5 cycles, ksi	112	85	78	U
10^7 cycles, ksi	92	77	70	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	110	92	80	U
10^5 cycles, ksi	53	44	43	U
10^7 cycles, ksi	35	35	35	U

Ti-6Al-4V ALLOY DATA
(Continued)

Properties	RT	400	600	800
	Temperature, F			
Creep (transverse)				
0.2% plastic deformation, 100 hr., ksi	NA	82	88	46
0.2% plastic deformation, 1000 hr., ksi	NA	81	84	30
Stress Rupture (transverse)				
Rupture, 100 hr., ksi	NA	102.5	92	82
Rupture, 1000 hr., ksi	NA	102	91.5	70
Stress Corrosion (transverse)(g)				
80% TYS, 1000 hr., maximum	no cracks			
Coefficient of Thermal Expansion				
5.0×10^{-6} in./in./F (RT to 800 F)				
Density				
0.160 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests in each direction.

(e) Specimens were compact tension type. Tests did meet the P_{max} P_Q requirement but not the size requirement of E399-72. Specimen strength ratios (R_{sc}) were calculated and are 1.28 for L-T specimens; 1.22 for T-L specimens.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson Theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3½% NaCl.

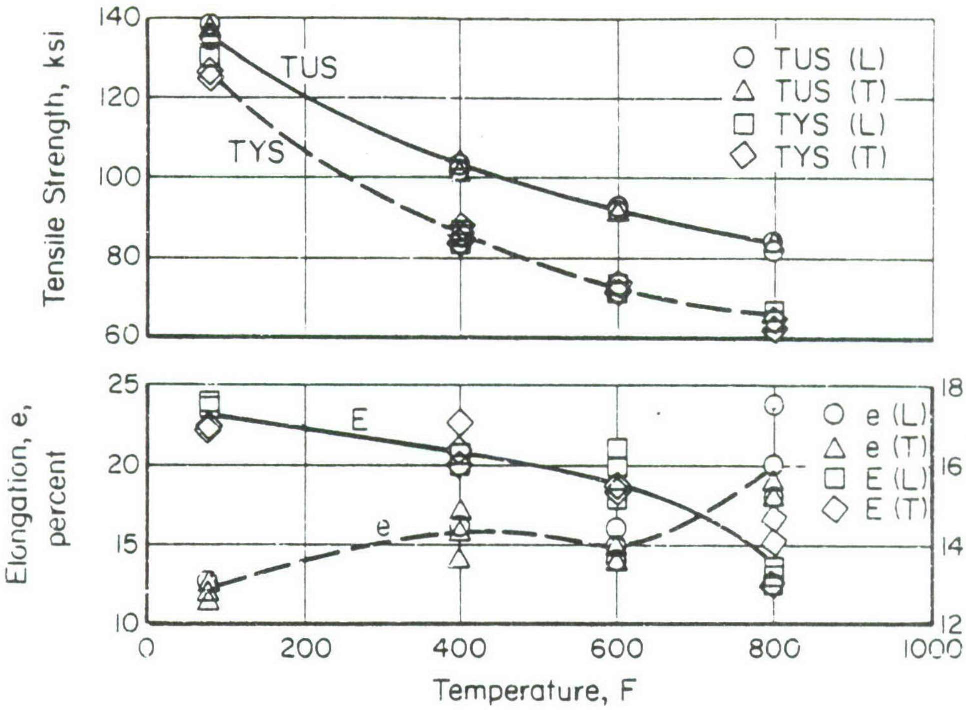


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA-ANNEALED Ti-6Al-4V ALLOY PLATE

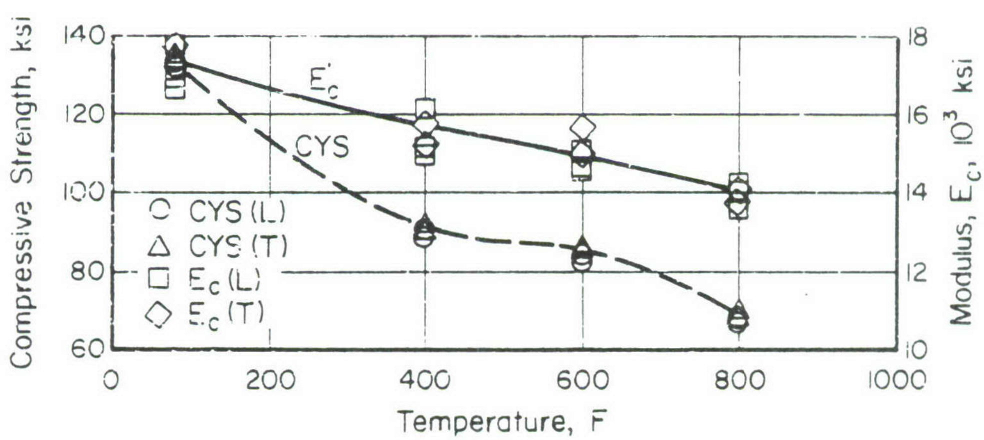


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF BETA-ANNEALED Ti-6Al-4V ALLOY PLATE

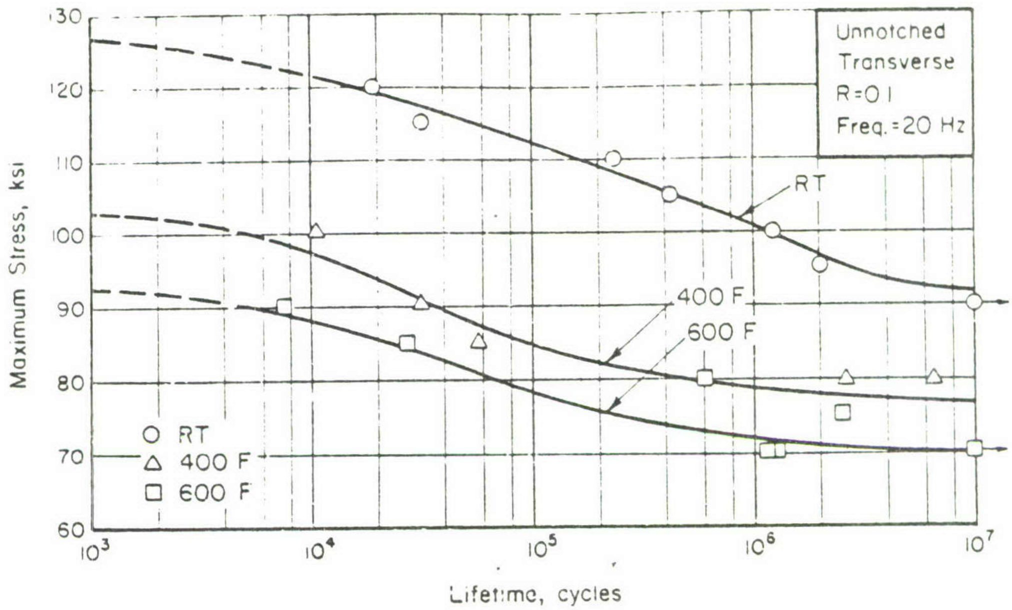


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED BETA-ANNEALED Ti-6Al-4V ALLOY PLATE

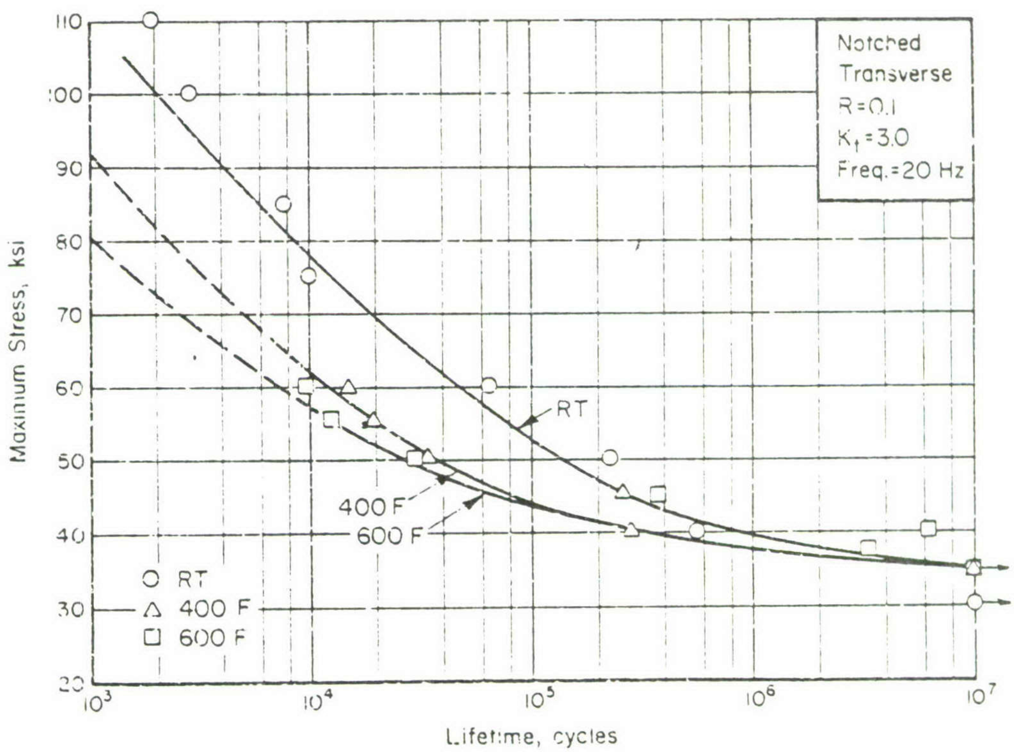


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) BETA-ANNEALED Ti-6Al-4V ALLOY PLATE

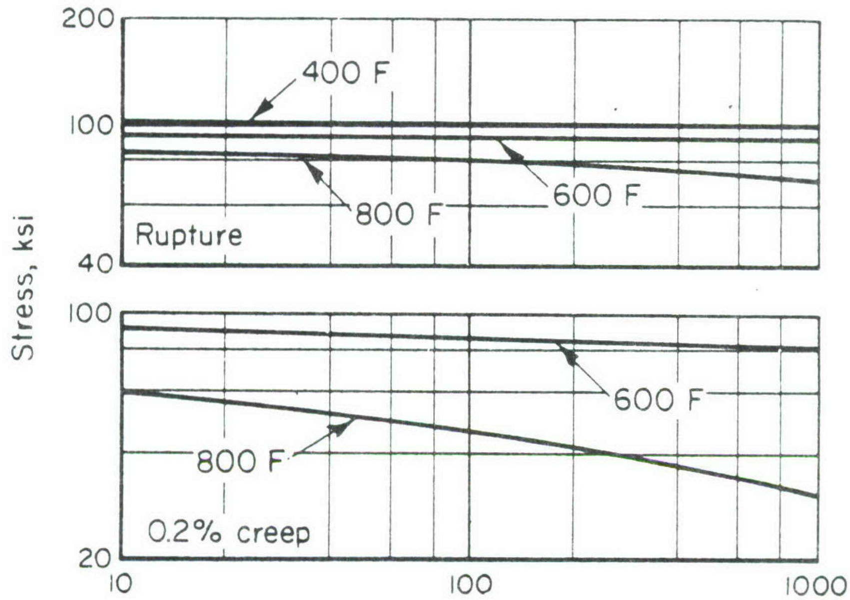


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR BETA-ANNEALED Ti-6Al-4V ALLOY PLATE (TRANSVERSE)

Ti-6Al-4V Isothermal Forging

Material Description

Application of the isothermal forging concept to titanium alloys has been investigated on a laboratory scale for many years. The material evaluated on this program came from an Air Force sponsored program (F33615-71-C-1264) at the Ladish Company. The specific goal was to develop isothermal forging technology as a process that will yield titanium airframe parts having surfaces which are "net", or which require no past-forging machining. The results of this program have been published in AFML-TR-74-123 from which additional information regarding this material may be obtained.

Processing and Heat Treating

The stabilizer rib from which the specimens were machined was of varying thickness and complex shape. All specimens were sectioned from the forging in the transverse direction. Specimens were tested in the as-received (annealed) condition.

Ti-6Al-4V Alloy Data[a]

Condition: Isothermally Forged and Annealed

Thickness: Various

Properties	Temperature, F RT	400	600	800
Tension				
TUS (transverse), ksi	143.9	110.5	99.8	87.4
TYS (transverse), ksi	136.3	102.2	93.4	78.3
e (transverse), percent in 1 in.	17.0	17.5	18.5	21.5
RA (transverse), percent	45.7	47.7	54.1	62.3
E (transverse), 10^3 ksi	16.4	15.2	14.5	12.9
Compression				
CYS (transverse), ksi	135.9	101.4	93.2	79.6
E_c (transverse), 10^3 ksi	16.5	15.4	13.9	12.9
Shear				
SUS (transverse), ksi	97.2	U[c]	U	U
Impact				
V-notch Charpy, ft.lbs. (transverse)	16.9[d]	U	U	U
Fracture Toughness				
K_{Ic}, ksi $\sqrt{in.}$	59.0[e]	U	U	U
Axial Fatigue (transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	135	110	95	U
10^5 cycles, ksi	128	105	89	U
10^7 cycles, ksi	75	80	73	U
Notched				
10^3 cycles, ksi	65	65	65	U
10^5 cycles, ksi	46	50	43	U
10^7 cycles, ksi	31	28	35	U

Ti-6Al-4V Alloy Data (Continued)

Properties	Temperature, F			
	RT	400	600	800
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	98	74	21
0.2% plastic deformation, 1000 hr, ksi	NA	96	70	11
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	112	102	101
Rupture, 1000 hr, ksi	NA	111	101	57
Stress Corrosion (transverse)(g)				
80% TYS, 1000 hr, maximum				
Coefficient of Thermal Expansion				
5.0×10^{-6} in./in./F (RT to 800 F)				
Density				
0.160 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Compact tension type specimen.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

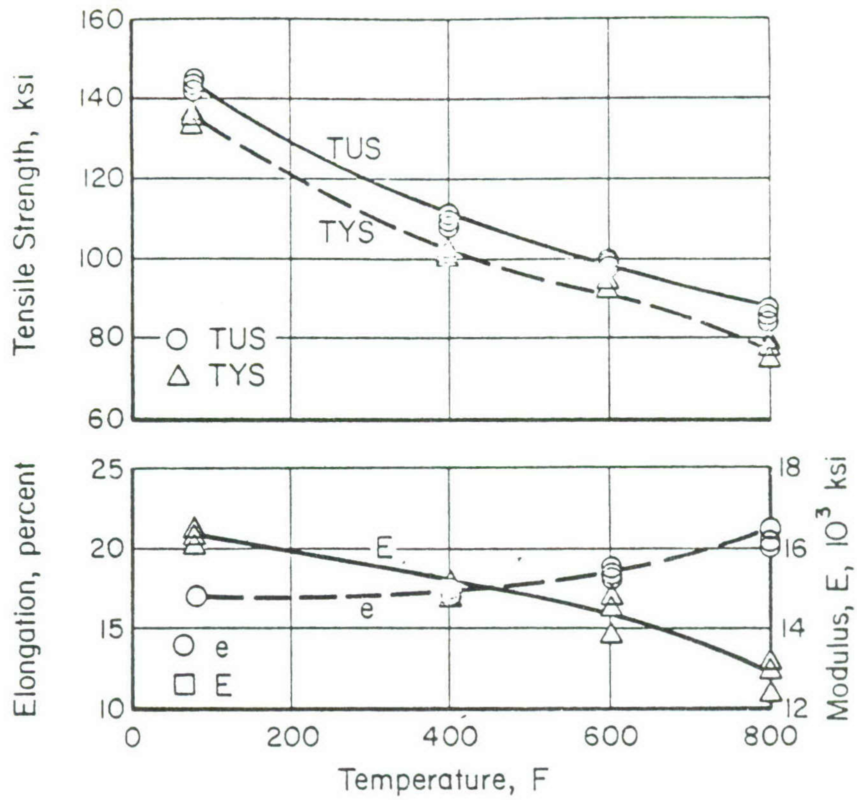


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V ISOTHERMAL FORGINGS

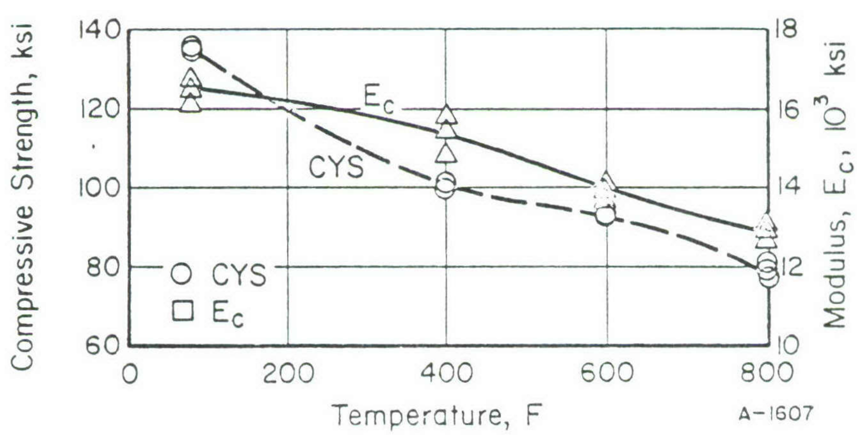


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V ISOTHERMAL FORGINGS

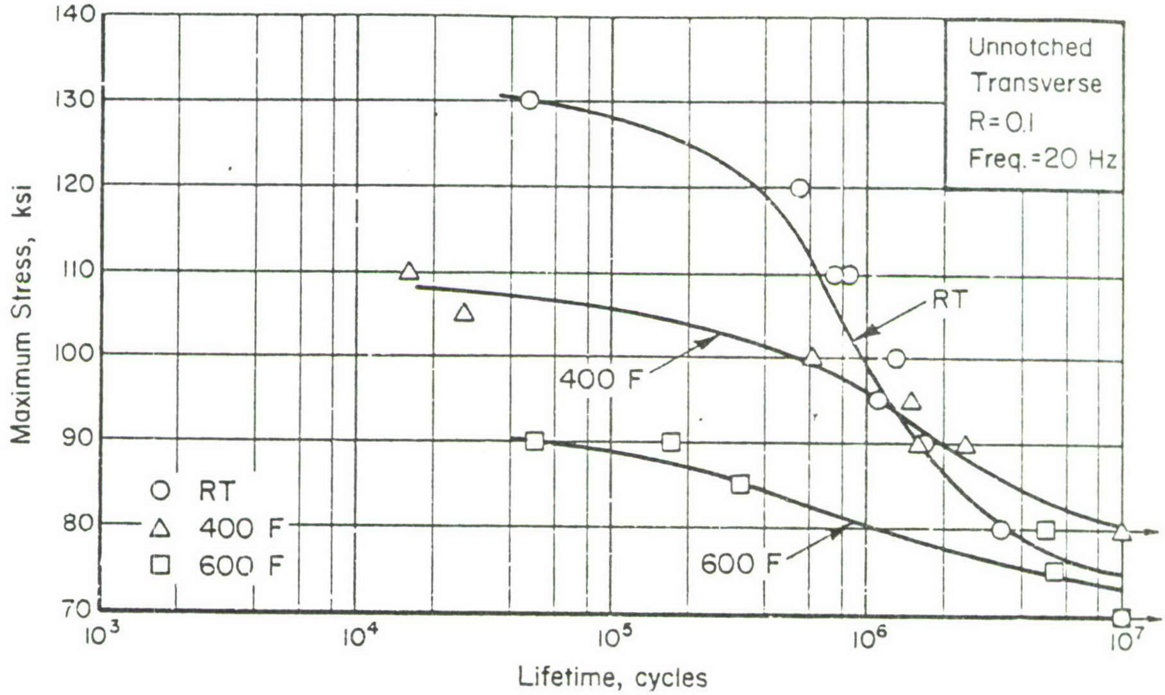


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-4V ISOTHERMAL FORGINGS

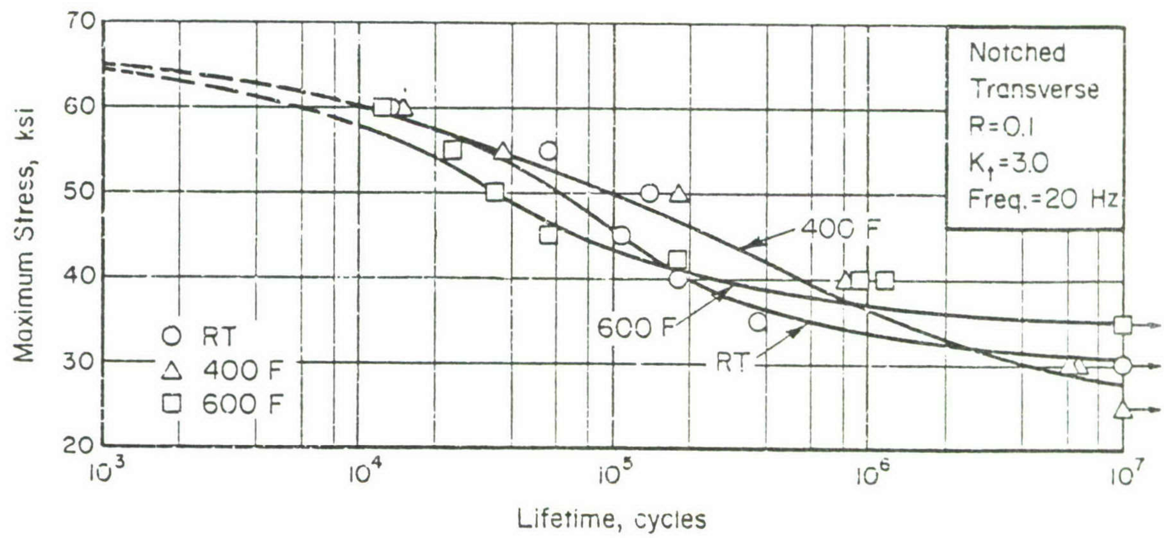


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6A-4V ISOTHERMAL FORGINGS

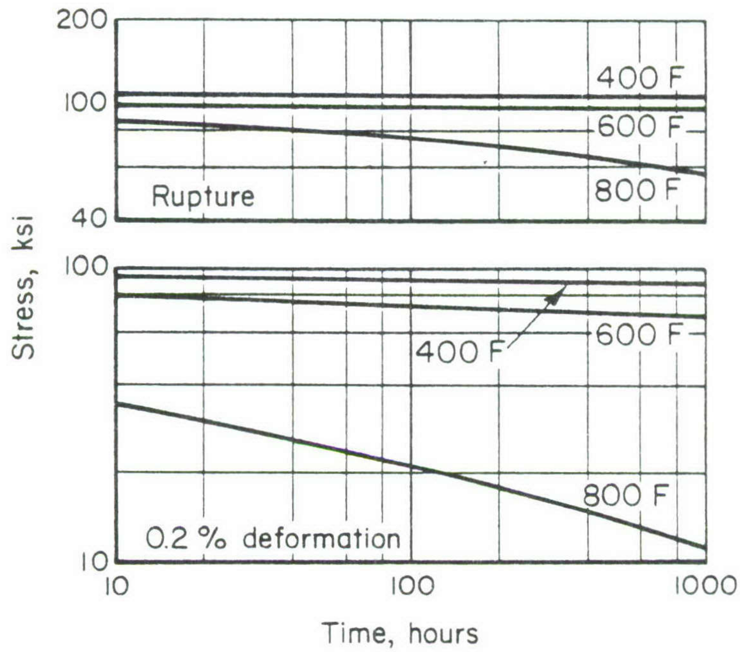


FIGURE 5. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V ISOTHERMAL FORGINGS

Ti-6Al-4V Alloy Castings

Material Description

Ti-6Al-4V castings have been utilized in airframe construction for a number of years, primarily in simple shapes and in unstressed or low stress areas. Recently, more complex shapes have been used as confidence in casting properties has increased. One of the primary reasons is that parts can be cast to a finished or near-finished shape instead of being machined to size from a large forging or thick plate.

The material used for this evaluation was cast, wedge shaped, plates approximately 5 inches by 6 1/2 inches and tapering from about 1 inch to 1/2 inch. The material was from TiTech International casting Heat Number 6-4 2119 and had the following composition:

Chemical Composition	Percent
Carbon	.028
Oxygen	.18
Hydrogen	.0027
Nitrogen	.015
Aluminum	5.90
Vanadium	3.90
Iron	.10
Titanium	Balance

Processing and Heat Treating

The specimens were all machined in one direction from the cast plates described above. The material was received in the annealed condition and no further heat treating was done.

Ti-6Al-4V Alloy Casting Data[a]

Condition: Annealed
Thickness: 0.5 to 1 inch

Properties	Temperature, F RT	400	600	800
Tension				
TUS (longitudinal), ksi	137.8	100.8	84.8	77.5
TYS (longitudinal), ksi	130.4	88.2	69.8	63.8
e (longitudinal), percent in 1 in.	6.5	10.2	12.0	12.0
RA (longitudinal), percent	11.2	19.0	24.3	28.4
E (longitudinal), 10^3 ksi	17.2	16.8	15.2	15.1
Compression				
CYS (longitudinal), ksi	137.5	92.9	74.6	67.5
E_c (longitudinal), 10^3 ksi	16.5	15.6	14.9	13.5
Shear				
SUS (longitudinal), ksi	92.8[b]	U[c]	U	U
Impact				
V-notch Charpy, ft.lbs. (longitudinal)	16.2[d]	U	U	U
Fracture Toughness	(c)	U	U	U
Axial Fatigue (longitudinal)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	130	130	84	U
10^5 cycles, ksi	70	63	60	U
10^7 cycles, ksi	44	39	37	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	90	82	76	U
10^5 cycles, ksi	58	49	44	U
10^7 cycles, ksi	41	29	27	U

Properties	Temperature, F			
	RT	400	600	800
Creep (longitudinal)				
0.2% plastic deformation, 100 hr, ksi	NA	77	81	45
0.2% plastic deformation, 1000 hr, ksi	NA	76	77	25
Stress Rupture (longitudinal)				
Rupture, 100 hr, ksi	NA	88	82	72
Rupture, 1000 hr, ksi	NA	87	81	69
Stress Corrosion (longitudinal)(g)				
80% TYS, 1000 hr, maximum	no cracks			
Coefficient of Thermal Expansion				
5.0×10^{-6} in./in./F (RT to 800 F)				
Density				
0.160 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) Material thickness was not sufficient for valid test results.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(g) Room-temperature three-point bend test. Alternate immersion in 3½% NaCl.

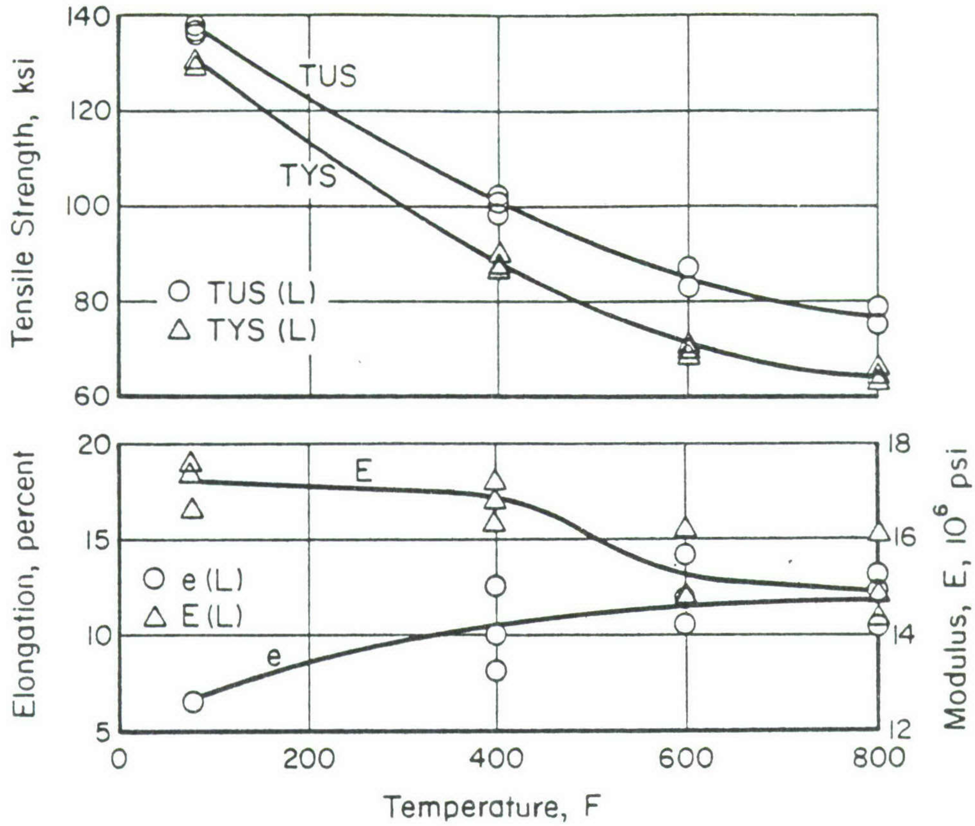


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED Ti-6Al-4V CASTINGS

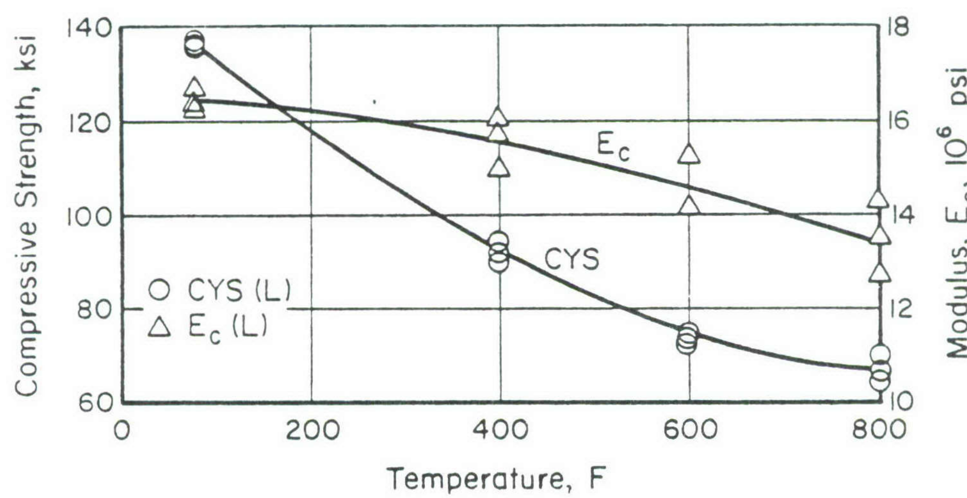


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF ANNEALED Ti-6Al-4V CASTINGS

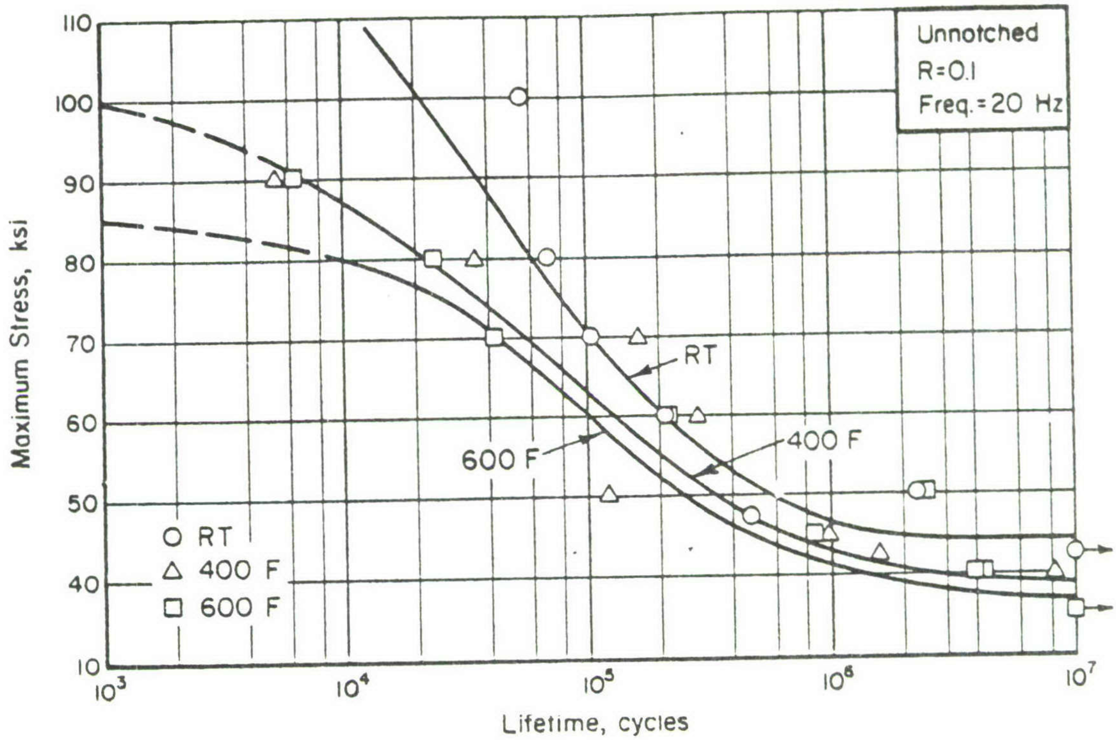


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ANNEALED Ti-6Al-4V CASTINGS

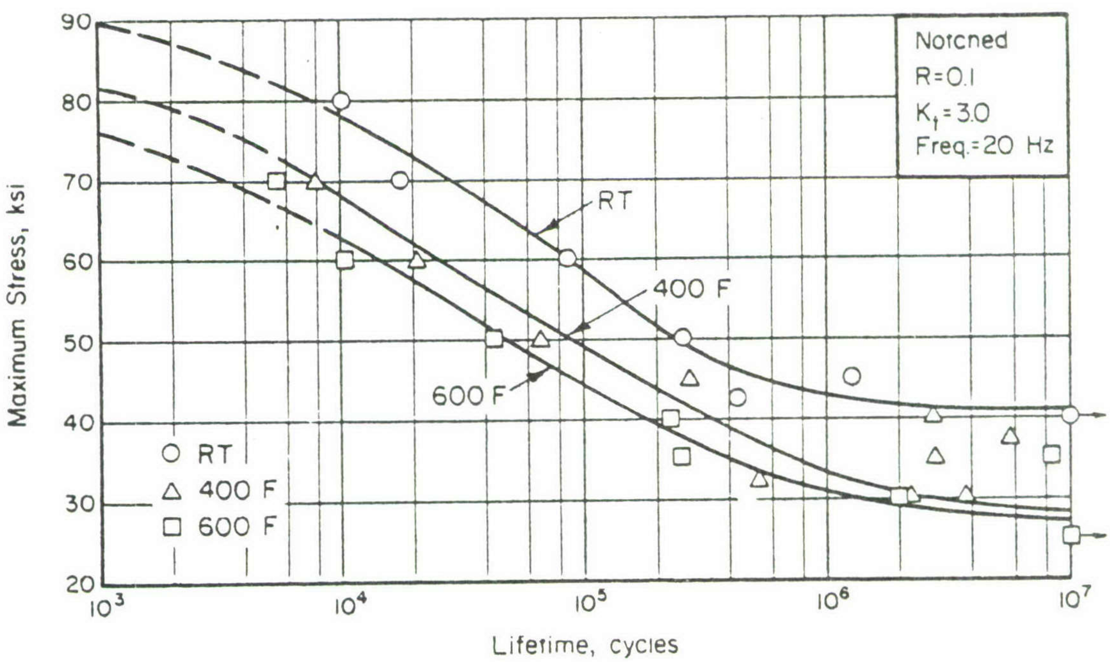


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) ANNEALED Ti-6Al-4V CASTINGS

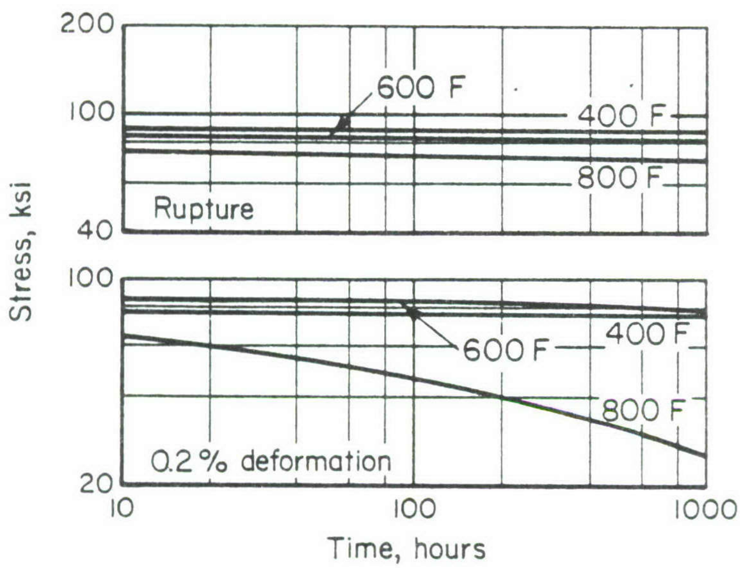


FIGURE 5. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR ANNEALED Ti-6Al-4V CASTINGS

Incoloy 903 Alloy

Material Description

Incoloy alloy 903 is a precipitation-hardenable nickel-iron-cobalt alloy whose outstanding characteristics are a constant low coefficient of thermal expansion, a constant modulus of elasticity, and high strength. Because the alloy contains no chromium, oxidation resistance may become a consideration for some high temperature applications.

The material used for this evaluation was a .0635-inch-thick sheet from Huntington Alloys Heat No. HH25A9UK with the following composition:

Chemical Composition	Percent
Carbon	0.03
Manganese	0.16
Iron	40.92
Sulfur	0.004
Silicon	0.07
Nickel	38.08
Aluminum	0.88
Titanium	1.61
Cobalt	15.22
Columbium plus Tantalum	3.01

Processing and Heat Treating

The sheet was received in the annealed condition and was heat treated as follows: 1325 F, 8 hours, furnace cool at 100 F per hour to 1150, held for 8 hours, air cool.

Incoloy 903 Alloy Data[a]

Condition: Heat Treated
Thickness: .0635 inch

Properties	Temperature, F RT	800	1000	1200
Tension				
TUS (longitudinal), ksi	191.9	170.7	166.6	130.6
TUS (transverse), ksi	193.0	170.1	163.5	131.6
TYS (longitudinal), ksi	155.5	140,8	134.8	116.7
TYS (transverse), ksi	165.0	142.6	135.6	120.4
e (longitudinal), percent in 2 in.	13.7	17.3	17.2	16.5
e (transverse), percent in 2 in.	16.0	15.8	14.7	17.3
E (longitudinal), 10^3 ksi	24.7	21.6	22.6	21.4
E (transverse), 10^3 ksi	25.8	22.2	22.3	21.1
Compression				
CYS (longitudinal), ksi	167.0	152.2	141.4	122.5
CYS (transverse), ksi	174.2	160.9	145.6	125.1
E_c (longitudinal), 10^3 ksi	25.2	22.8	23.0	21.4
E_c (transverse), 10^3 ksi	24.3	23.7	23.2	22.2
Shear[b]				
SUS (longitudinal), ksi	123.9	U[c]	U	U
SUS (transverse), ksi	127.8	U	U	U
Fracture Toughness				
K_c (T-L) ksi$\sqrt{\text{in.}}$	244.5[d]			
Axial Fatigue (Transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	154	140	131	U
10^5 cycles, ksi	125	112	98	U
10^7 cycles, ksi	84	73	67	U
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	120	100	100	U
10^5 cycles, ksi	73	64	64	U
10^7 cycles, ksi	46	44	44	U

	Temperature, F			
	RT	800	1000	1200
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi		(no creep)		15
0.2% plastic deformation, 1000 hr, ksi				14
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	NA	48	50	31
Rupture, 1000 hr, ksi	NA	35	44	15
Stress Corrosion (transverse)(f)				
80% TYS, 1000 hr, maximum	no cracks			
Coefficient of Thermal Expansion				
5.6×10^{-6} in./in./F				
Density				
0.294 lb./in.^{3}				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Sheet-shear type specimen; average of 3 tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Specimens were 18 x 36 with a center flaw. Value is average of 4 tests.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3½% NaCl.

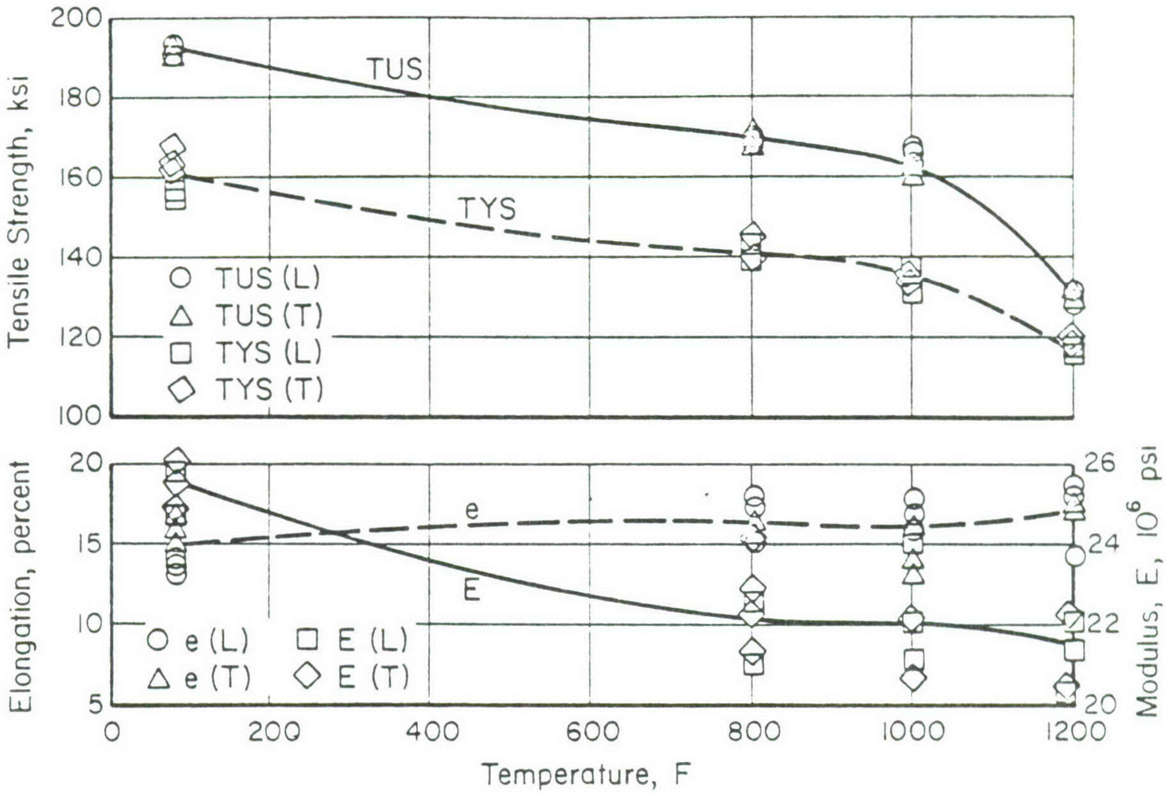


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HEAT-TREATED INCOLOY 903 SHEET

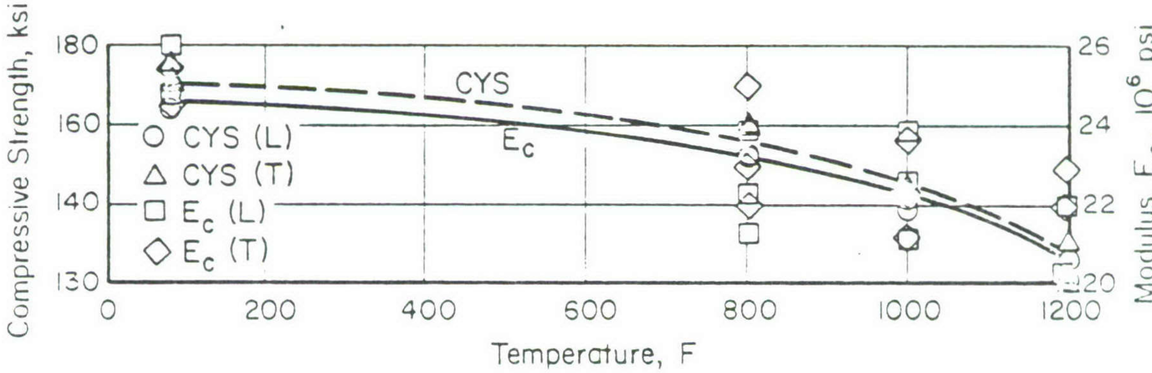


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF HEAT-TREATED INCOLOY 903 SHEET

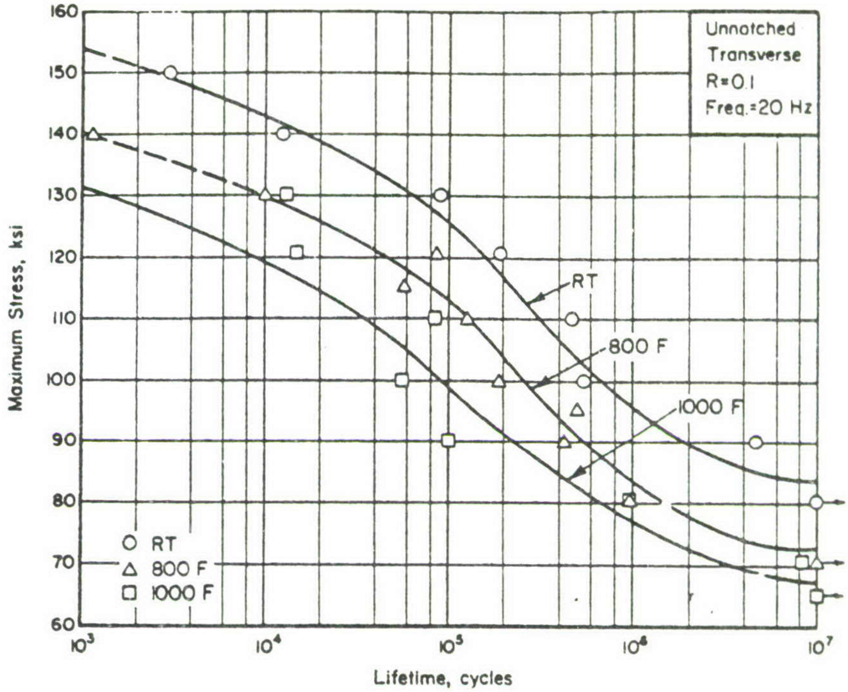


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED HEAT-TREATED INCOLOY 903 SHEET

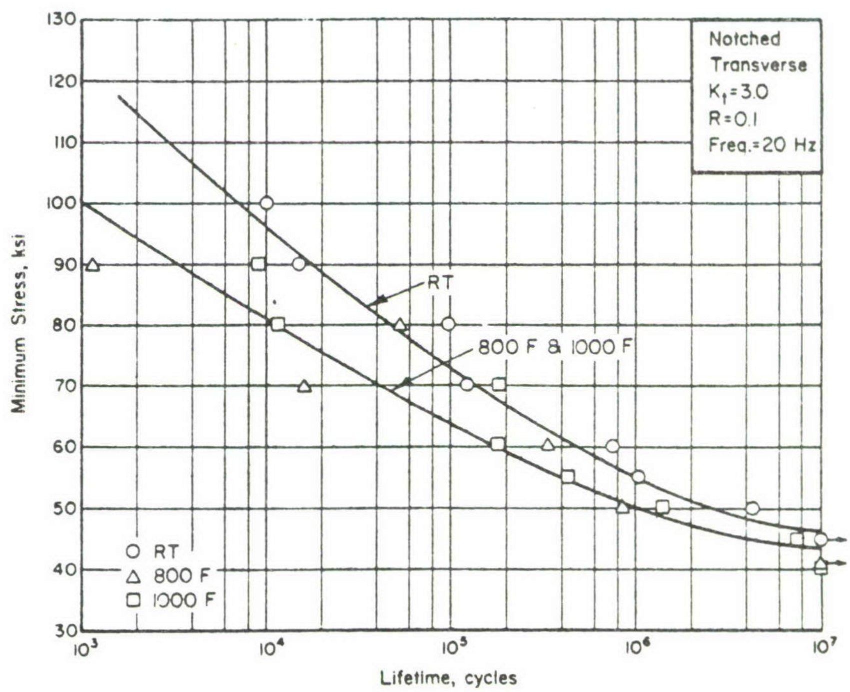


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) HEAT-TREATED INCOLOY 903 SHEET

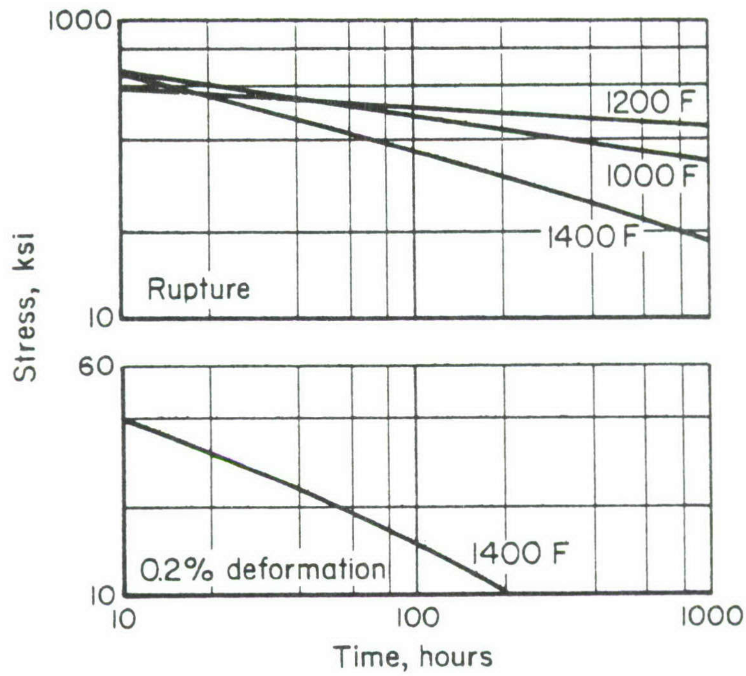


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR HEAT-TREATED INCOLOY 903 SHEET (TRANSVERSE)

201-T7 Aluminum Castings

Material Description

201 is a recently developed heat-treatable, high strength aluminum casting alloy which contains copper, silver, magnesium, and titanium. Premium quality castings made from this alloy have exhibited improved mechanical strength properties when compared to castings of other conventional aluminum alloys. The alloy can be cast by sand, permanent mold, or investment casting techniques.

The castings used for this evaluation were actual production parts used in airframe construction.

Processing and Heat Treating

The alloy was tested in the as-received -T7 condition.

201-T7 Alloy Data[a]

Condition: -T7
Thickness: Various

Properties	Temperature, F			
	RT	300	400	500
<u>Tension</u>				
TUS (longitudinal), ksi	67.1	56.8	48.4	29.8
TYS (longitudinal), ksi	60.0	49.4	46.2	28.3
e (longitudinal), percent in 2 in.	4.7	7.2	9.5	14.5
E (longitudinal), 10^3 ksi	10.5	9.6	8.8	8.0
<u>Compression</u>				
CYS (longitudinal), ksi	60.9	53.6	48.2	30.9
E_c (longitudinal), 10^3 ksi	11.1	9.9	9.7	9.0
<u>Shear</u>				
SUS (longitudinal), ksi	39.3[b]	U[c]	U	U
<u>Impact</u>				
V-notch Charpy, ft.lbs. (longitudinal)	5.0[d]	U	U	U
<u>Axial Fatigue (transverse)</u>[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	62	62	62	U
10^5 cycles, ksi	37	36	35	U
10^7 cycles, ksi	31	27	25	
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi	54	54	50	U
10^5 cycles, ksi	22	21	19	U
10^7 cycles, ksi	16	14	12	U

201-T7 Alloy Data (Continued)

Properties	RT	300	400	500
	Temperature, F			
Creep (transverse)				
0.2% plastic deformation, 100 hr, ksi	U	43	34	8
0.2% plastic deformation, 1000 hr, ksi	U	41	19	4.5
Stress Rupture (transverse)				
Rupture, 100 hr, ksi	U	50	39	13
Rupture, 1000 hr, ksi	U	47	32	3.5
Stress Corrosion (transverse)(f)				
80% TYS, 1000 hr, maximum	no cracks			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of 4 tests.

(c) U, unavailable; NA, not applicable.

(d) Average of 6 tests.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) Room-temperature three-point bend test. Alternate immersion in 3 1/2% NaCl.

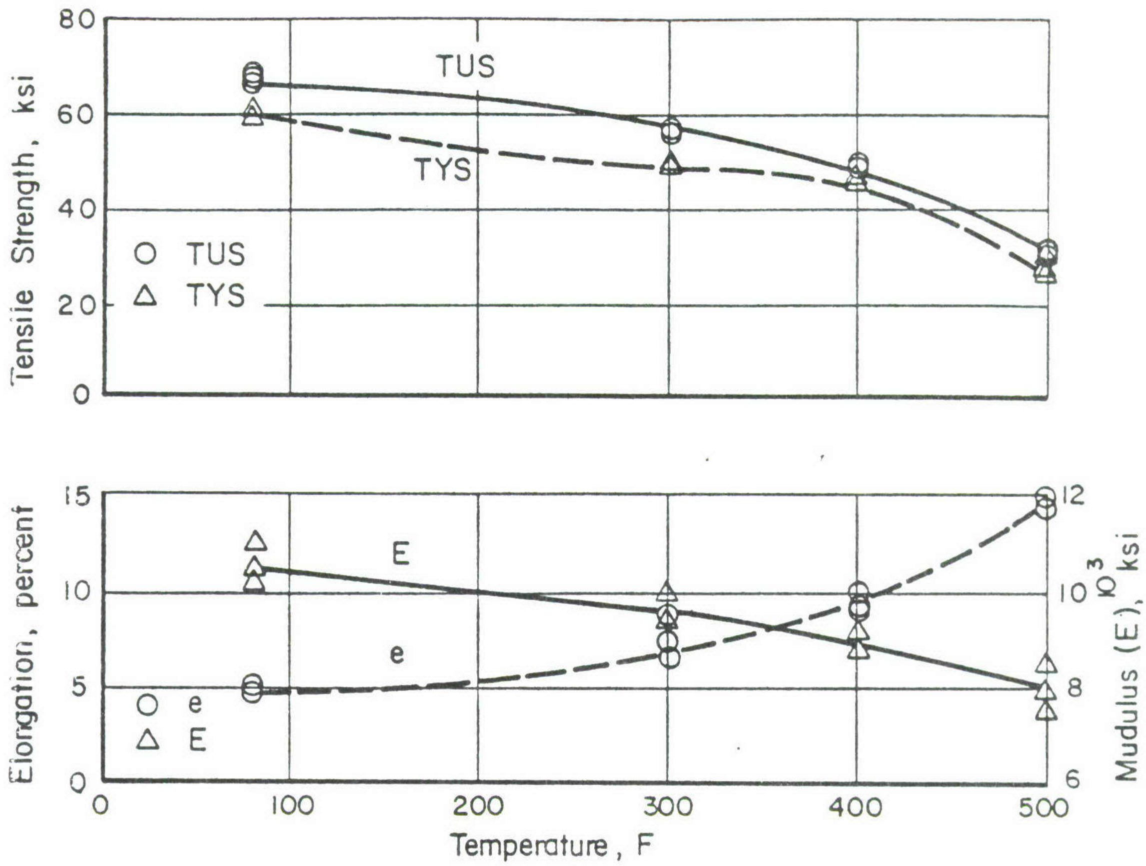


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 201-T7 ALUMINUM ALLOY CASTINGS

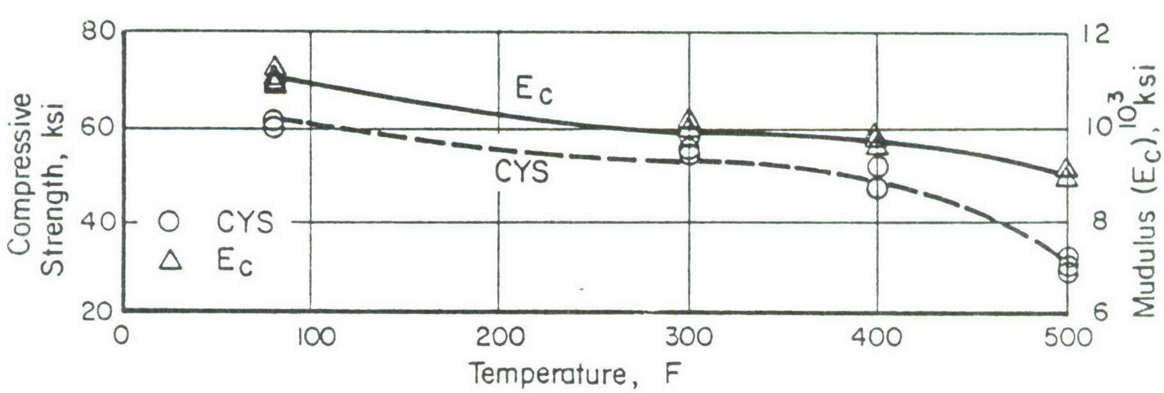


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 201-T7 ALUMINUM ALLOY CASTINGS

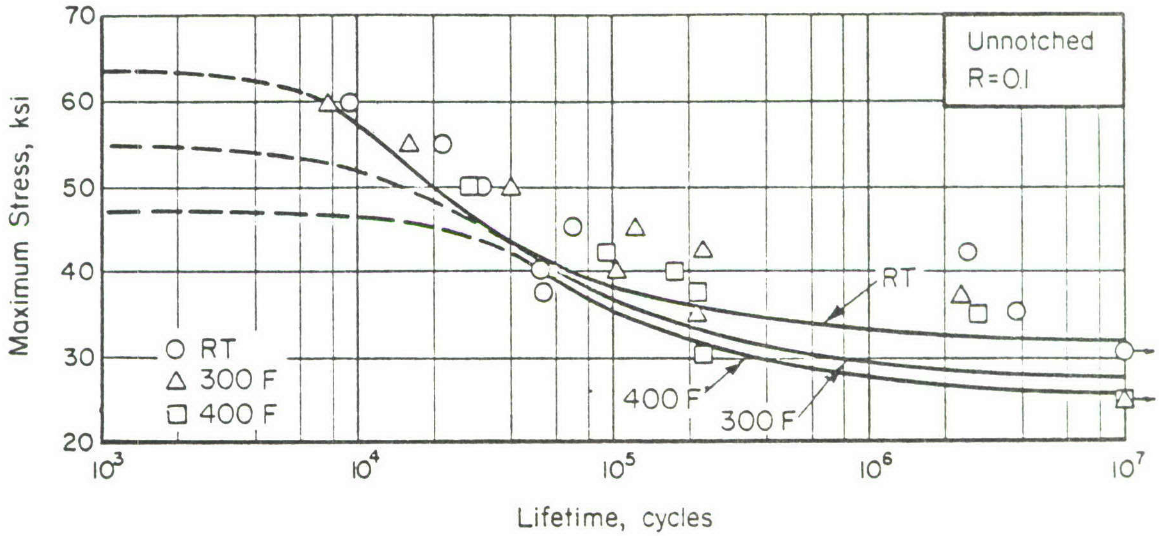


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 201-T7 ALUMINUM ALLOY CASTING

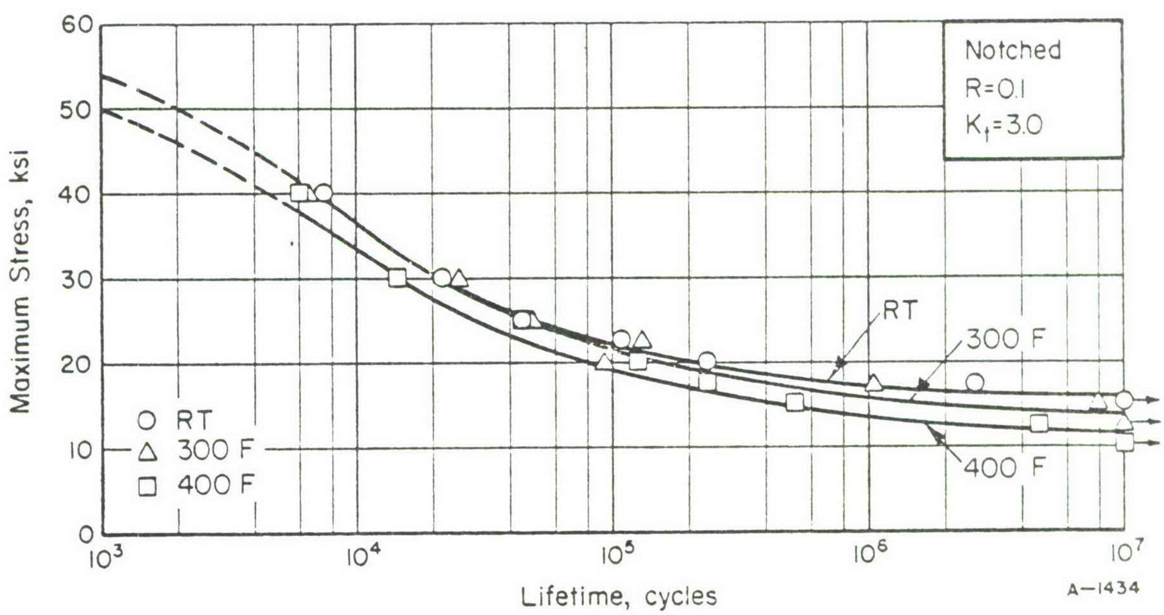


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 201-T7 ALUMINUM ALLOY CASTINGS

MP159 Multiphase Alloy

Material Description

MP159 Alloy is a recent addition to the Multiphase family of alloys developed by the Latrobe Steel Company. It possesses a unique combination of ultra high strength, ductility, and corrosion resistance. Through work strengthening and aging, the alloy exhibits tensile ultimate strength levels in excess of 265 ksi while maintaining reduction of area values greater than 30%. Excellent strength and ductility are also evident at elevated temperatures up to 1200 F. This alloy displays excellent resistance to crevice and stress corrosion in various hostile environments. Typical uses are fasteners and jet engine components.

The material used for this evaluation was .766-inch-diameter round bar from Latrobe Heat No. C52377. The material had the following composition:

Chemical Composition	Percent
Carbon	.014
Silicon	.01
Manganese	.01
Sulfur	.004
Phosphorus	.004
Iron	8.77
Chromium	18.95
Columbium	.64
Molybdenum	7.09
Cobalt	34.78
Titanium	2.99
Aluminum	.22
Nickel	Balance

Processing and Heat Treating

The material was received in the cold drawn-as drawn condition (48% work strengthed). After machining, the specimens received a 1225 F, 4 hour, air cool aging treatment.

MP159 Alloy Data[a]

Condition: Work Strengthened and Aged

Thickness: .766-Inch-Diameter Round Bar

Properties	Temperature, F RT	800	1200
Tension			
TUS (longitudinal), ksi	279.5	238.0	222.5
TYS (longitudinal), ksi	276.0	232.3	212.3
e (longitudinal), percent in 2 in.	6.3	5.8	5.0
RA (longitudinal), percent	27.7	29.0	15.7
E (longitudinal), 10^3 ksi	33.3	30.2	26.3
Compression			
CYS (longitudinal), ksi	283.5	233.9	215.1
E_c (longitudinal), 10^3 ksi	35.1	30.3	29.0
Shear[b]			
SUS (longitudinal), ksi	187.2	166.0	126.3
Impact			
V-notch Charpy, ft. lbs.	42.1[d]	U[c]	U
Axial Fatigue (longitudinal)			
Unnotched, R = 0.1			
10^3 cycles, ksi	270	235	218
10^5 cycles, ksi	212	212	200
10^7 cycles, ksi	118	118	140
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	160	135	105
10^5 cycles, ksi	70	70	70
10^7 cycles, ksi	30	50	60

(Continued)

Properties	Temperature, F RT	800	1200
Creep (transverse)			
0.2% plastic deformation, 100 hr, ksi	NA[c]	180	94
0.2% plastic deformation, 1000 hr, ksi	NA	165	68
Stress Rupture (transverse)			
Rupture, 100 hr, ksi	NA	196.5	149
Rupture, 1000 hr, ksi	NA	196	110
Stress Corrosion[e]			
80% TYS, 1000 hr maximum	no cracks		
Coefficient of Thermal Expansion			
8.7×10^{-6} in./in./F (80 - 1200 F)			
Density			
0.302 lbs./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests.

(e) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

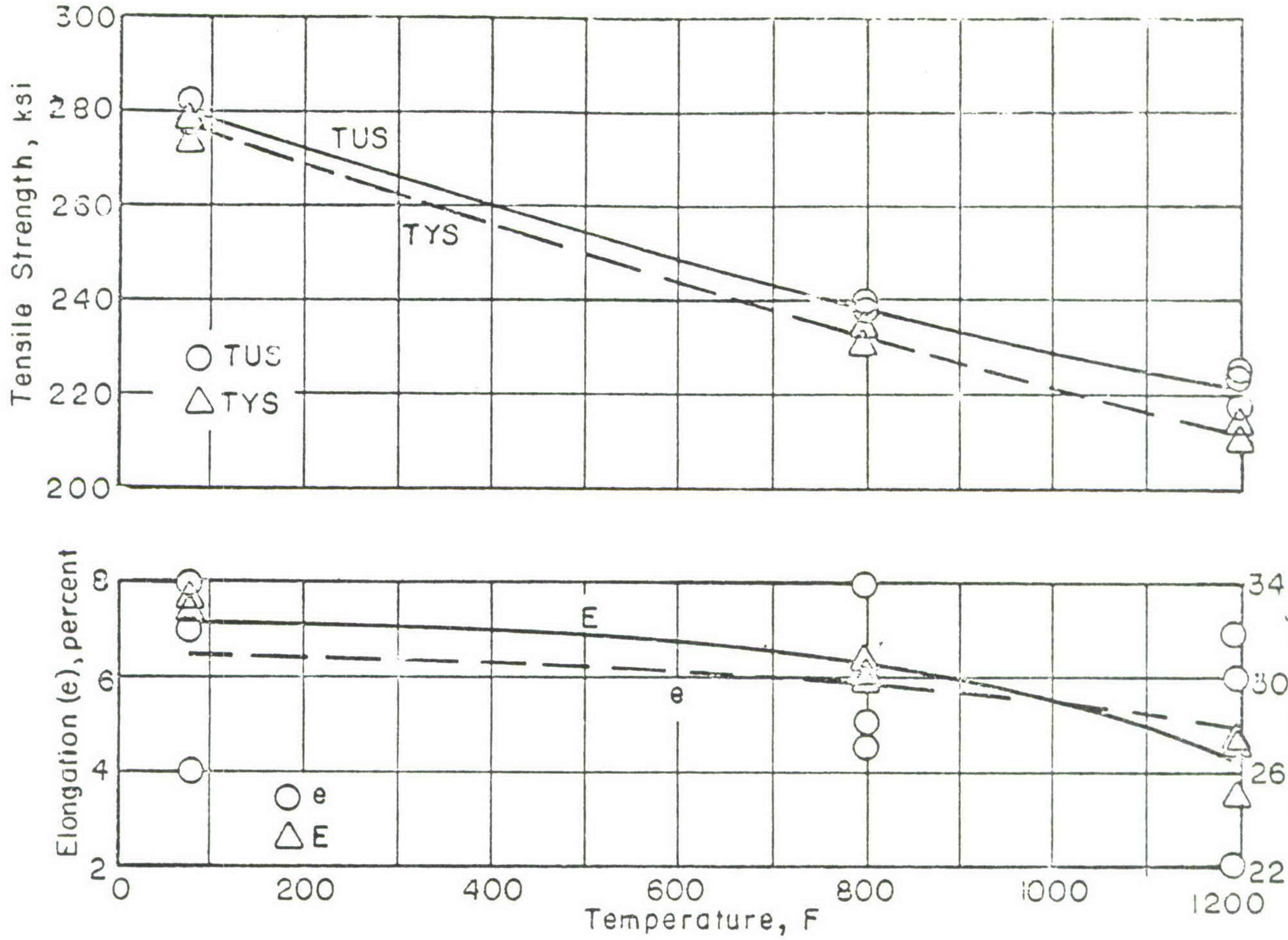


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

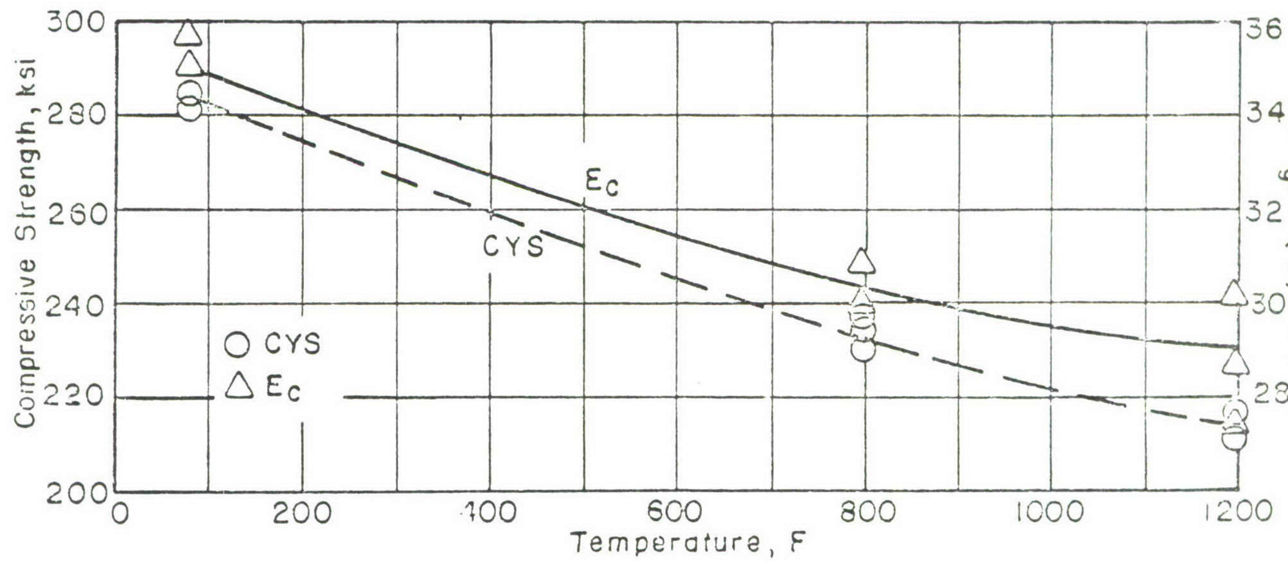


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

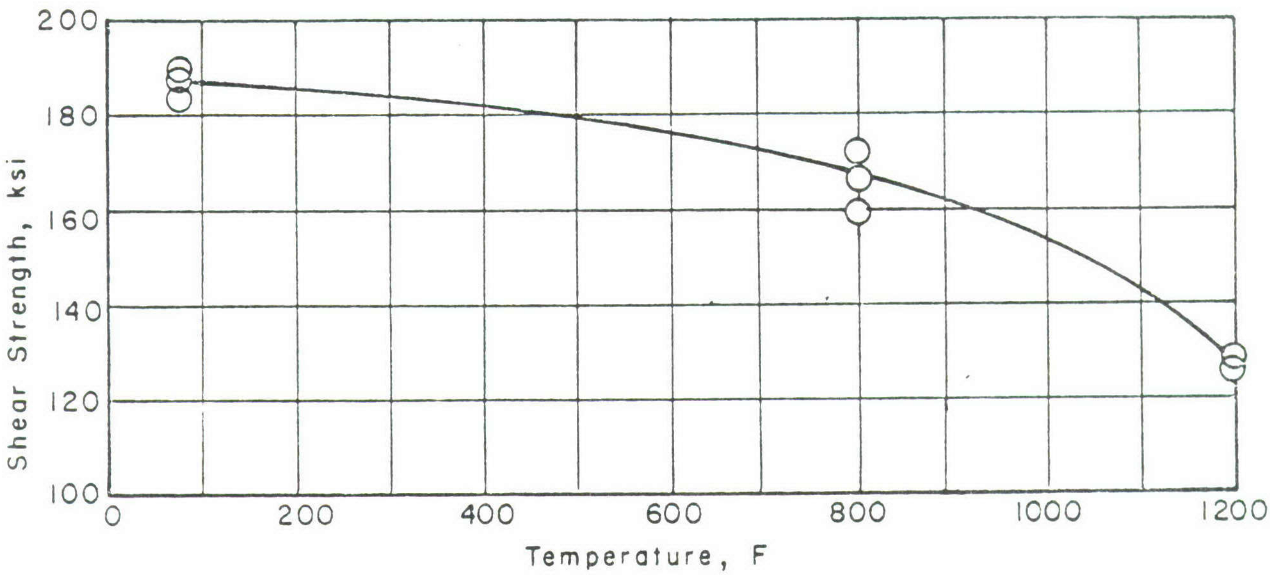


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF WORK STRENGTHENED AND AGED MP159 ALLOY BAR

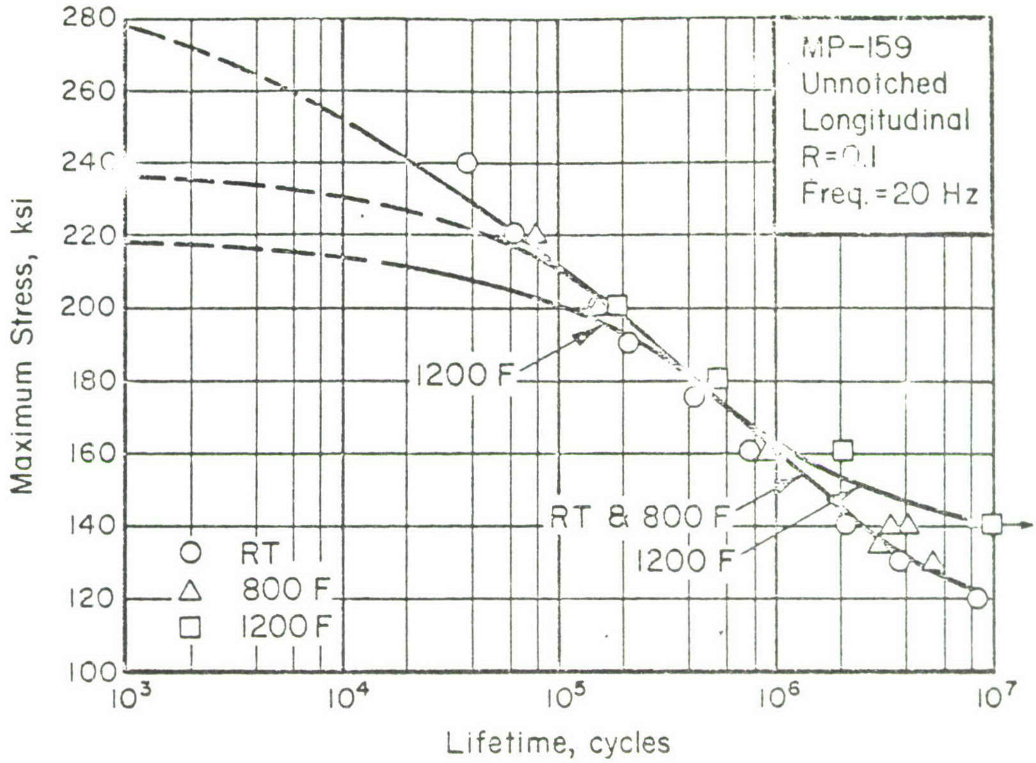


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED WORK STRENGTHENED AND AGED MP159 ALLOY BAR

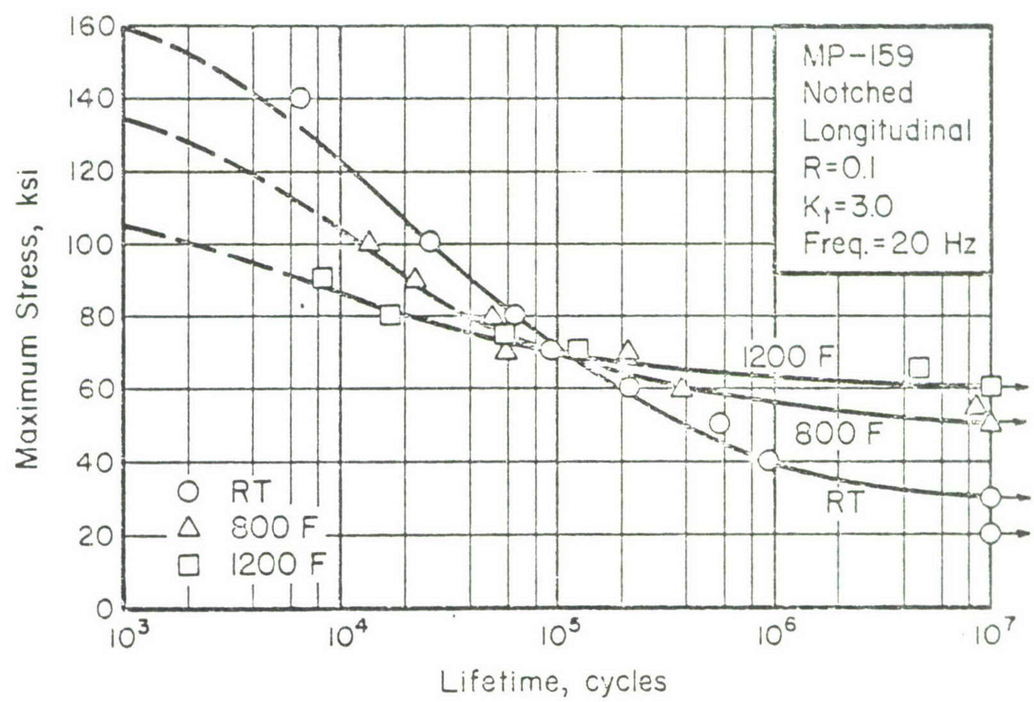


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) WORK STRENGTHENED AND AGED MP159 ALLOY BAR

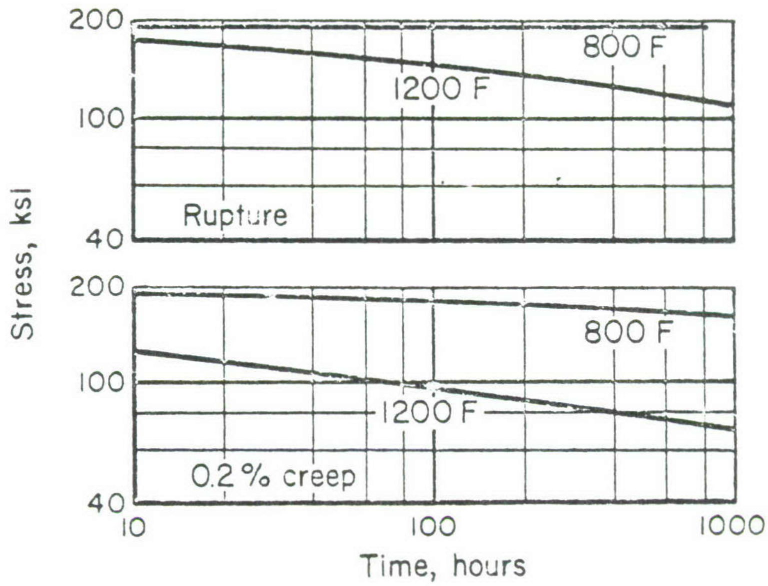


FIGURE 6. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR WORK STRENGTHENED AND AGED MP159 ALLOY BAR

Ti-6Al-2Sn-4Zr-2Mo Alloy

Material Description

This alloy is considered a super-alpha titanium alloy having an alpha-stabilized Ti-Al matrix solid solution strengthened by the additions of tin and zirconium. It has been primarily used in jet engine compressor parts and airframe skin components. It has good strength properties at elevated temperatures, and good creep properties and corrosion resistance.

Because of the current interest in titanium castings, the material chosen for this evaluation was 6 inch x 6½ inch cast wedges (tapered plates) manufactured by TiTech International and supplied by Rockwell International, Columbus Division. The composition was as follows:

Chemical Composition	Percent
C	.018
O	.168
H	.0047
N	.013
Al	6.02
Sn	2.04
Zr	3.80
Mo	2.07
Fe	.010
Si	.05

Processing and Heat Treating

The material was evaluated in the as-received as-cast condition.

Ti-6Al-2Sn-4Zr-2Mo Alloy Data[a]

Condition: As-Cast

Thickness: Tapered Wedge, 1 Inch to About ½ Inch

Properties	Temperature, F RT	400	800
<u>Tension</u>			
TUS, ksi	135.2	110.3	94.7
TYS, ksi	121.0	85.9	69.4
e, percent in 1 inch	10.0	10.2	12.5
RA, percent	17.2	18.5	23.7
E, 10^3 ksi	17.3	15.9	14.9
<u>Compression</u>			
CYS, ksi	135.6	94.8	77.4
E_c, 10^3 ksi	17.1	16.1	14.5
<u>Bearing</u>			
e/D = 1.5			
BUS, ksi	221.6	186.2	159.6
BYS, ksi	195.5	156.1	131.1
e/D = 2.0			
BUS, ksi	296.7	226.0	199.9
BYS, ksi	251.9	185.1	154.6
<u>Shear</u>[b]			
SUS, ksi	95.3	73.1	62.5
<u>Impact</u>			
V-notch Charpy, ft.lbs.	14.9	U[c]	U
<u>Fracture Toughness</u>[d]			
K_{Ic}, ksi $\sqrt{\text{in.}}$	59.4	U	U

(Continued)

Properties	Temperature, F RT	700	800
Axial Fatigue			
Unnotched, R = 0.1			
10^3 cycles, ksi	125	87	86
10^5 cycles, ksi	62	56	56
10^7 cycles, ksi	28	22	22
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	110	100	85
10^5 cycles, ksi	45	44	43
10^7 cycles, ksi	30	30	30
Creep			
0.2% plastic deformation, 100 hr, ksi	NA[(c)]	87	44
0.2% plastic deformation, 1000 hr, ksi	NA	79	35
Stress Rupture (transverse)			
Rupture, 100 hr, ksi	NA	92.5	35
Rupture, 1000 hr, ksi	NA	92	78
Stress Corrosion			
K_{Iscc}	(e)		
Coefficient of Thermal Expansion			
5.4×10^{-6} in./in./F (80 to 800 F)			
Density			
0.163 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests.

(c) U, unavailable; NA, not applicable.

(d) Average of six tests.

(e) No appreciable crack growth could be obtained to measure K_{Iscc}.

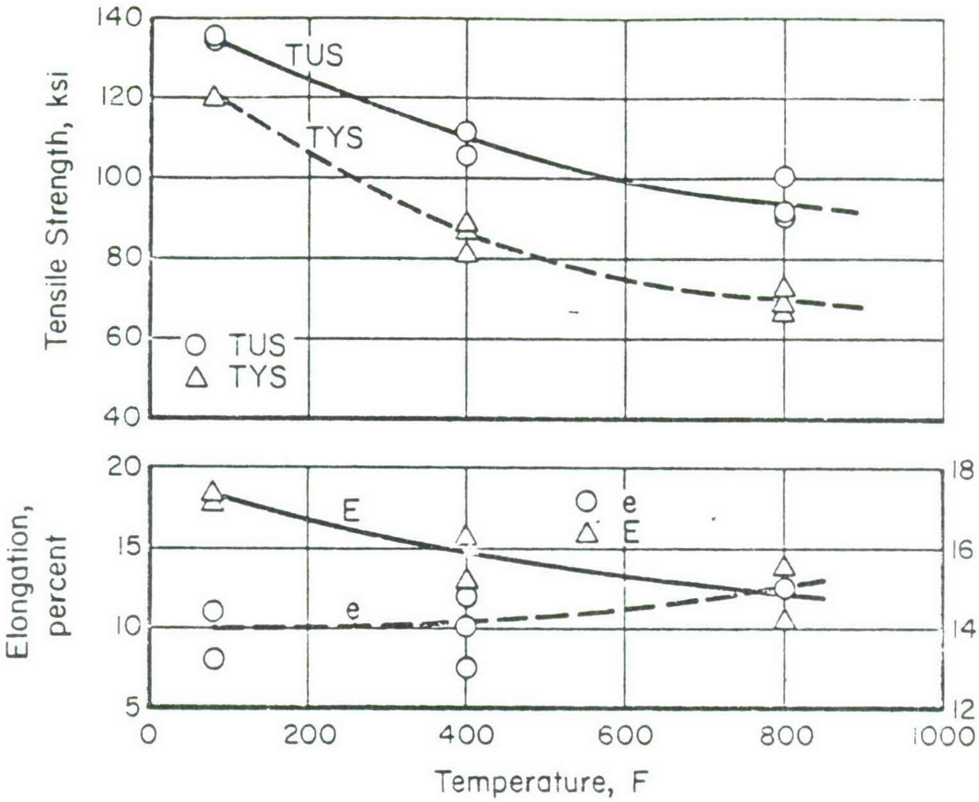


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

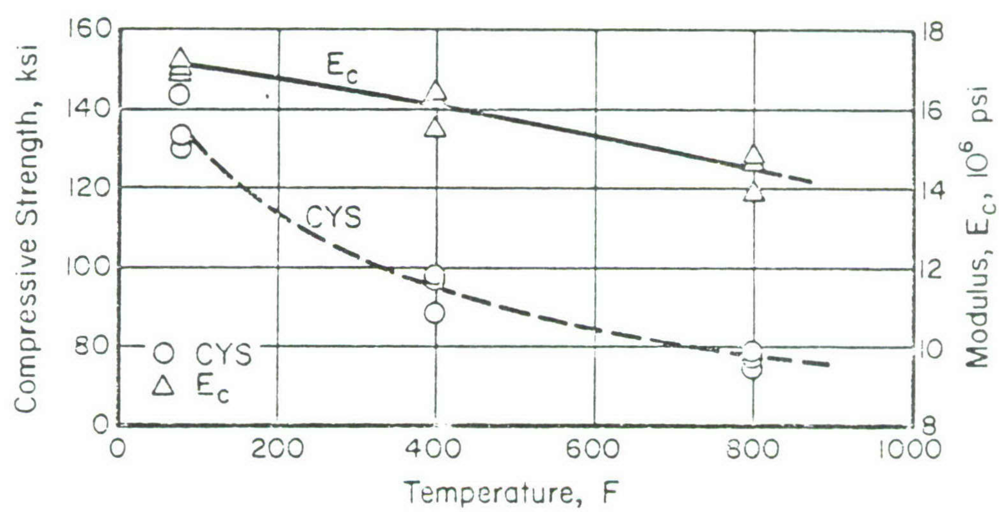


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

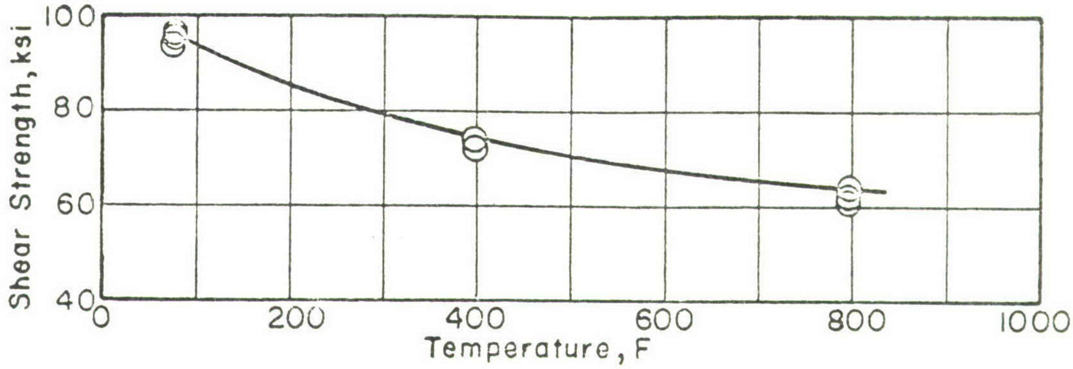


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTING

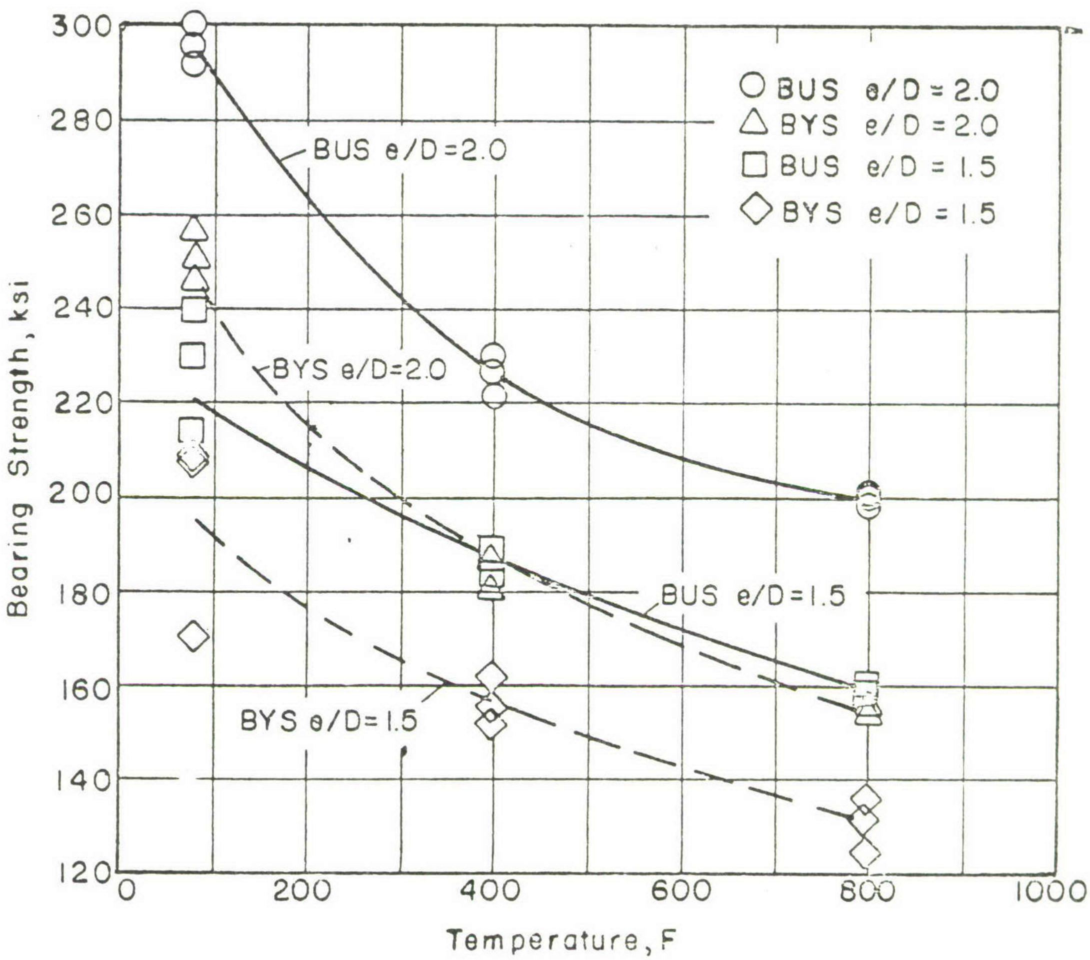


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

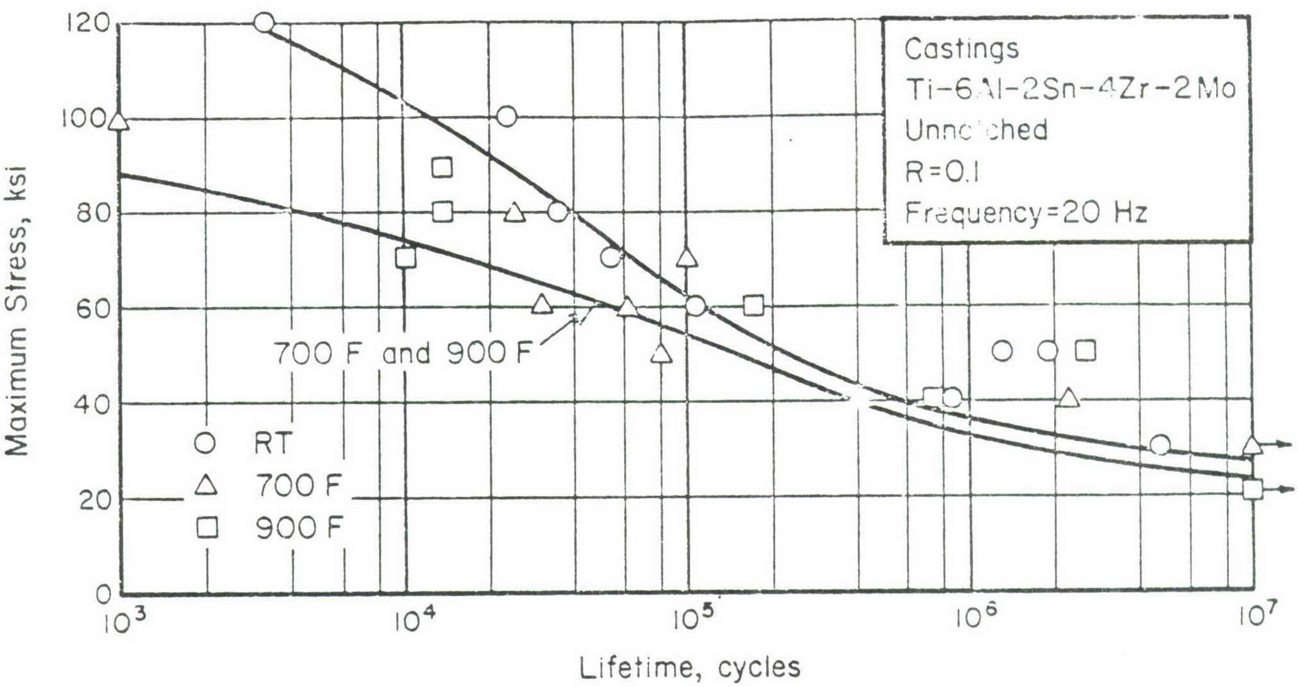


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

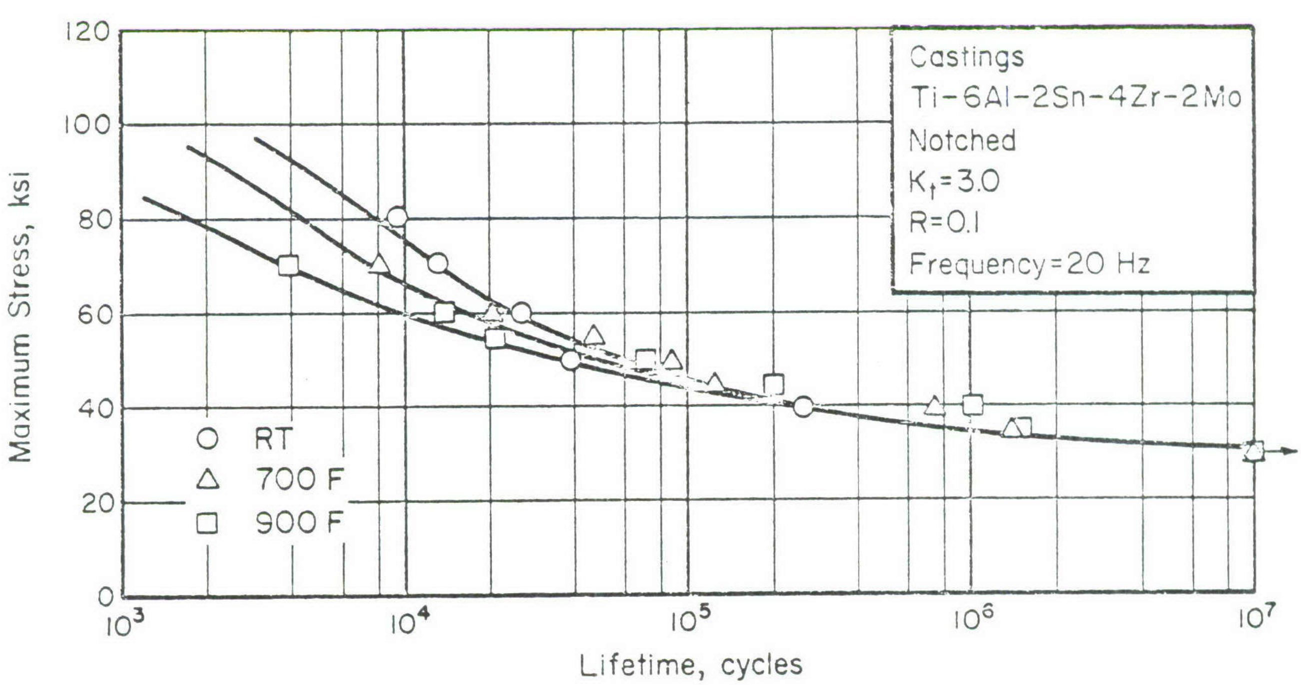


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

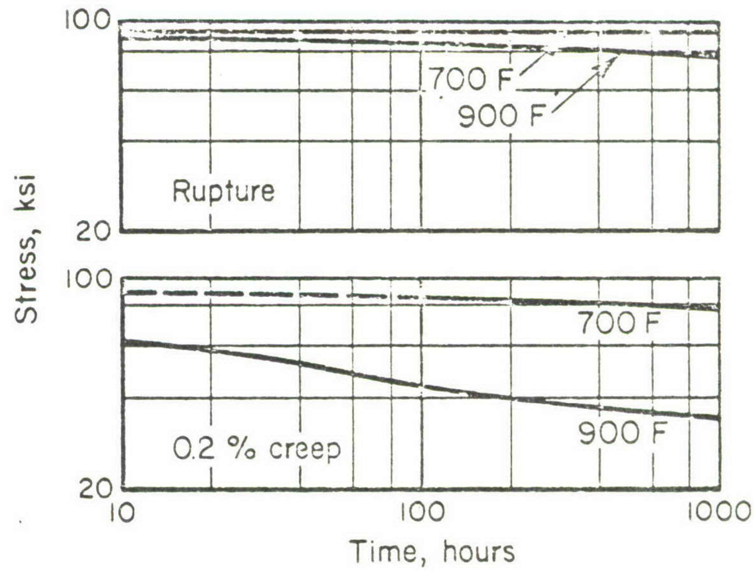


FIGURE 7. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-2Sn-4Zr-2Mo ALLOY CASTINGS

7175 Aluminum Alloy

Material Description

This aluminum alloy is a development of Alcoa and is primarily a high purity modification of the 7075 alloy. It was developed to provide improvements in mechanical properties, fracture toughness, and stress corrosion resistance over 7075. The material evaluated on this program was an extrusion about 3/4-inch thick by 24-inches wide by 24-inches long supplied by the Air Force.

Composition limits for 7175 are as follows:

Chemical Composition	Percent
Si	0.15 max
Fe	0.20 max
Cu	1.2 to 2.0
Mn	0.10 max
Cr	0.18 to 0.30
Zn	5.1 to 6.1
Ti	0.10 max
Mg	2.1 to 2.9
Others (Each)	0.05 max
Others (Total)	0.15 max
Al	balance

Processing and Heat Treating

The material was evaluated in the as-received -T73511 temper.

7175 Alloy Data[a]

Condition: -T73511

Thickness: ~ 3/4 x 24 x (L) Extrusion

Properties	Temperature, F RT	250	350
Tension			
TUS (longitudinal), ksi	77.1	62.3	46.8
TUS (transverse), ksi	76.3	61.4	46.2
TYS (longitudinal), ksi	66.3	60.2	41.0
TYS (transverse), ksi	64.9	58.9	38.0
e (longitudinal), percent in 1 inch	12.8	21.5	29.2
e (transverse), percent in 1 inch	12.0	19.7	26.7
RA (longitudinal), percent	35.5	50.9	60.0
RA (transverse), percent	27.6	45.0	54.9
E (longitudinal), 10^3 ksi	10.5	10.1	8.3
E (transverse), 10^3 ksi	10.9	10.6	8.6
Compression			
CYS (longitudinal), ksi	69.8	62.5	50.2
CYS (transverse), ksi	70.3	62.3	50.8
E_c (longitudinal), 10^3 ksi	10.1	10.1	9.6
E_c (transverse), 10^3 ksi	10.5	10.0	9.5
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	116.7	101.2	76.3
BUS (transverse), ksi	119.5	98.1	76.4
BYS (longitudinal), ksi	91.5	39.0	68.3
BYS (transverse), ksi	96.6	83.0	69.7
e/D = 2.0			
BUS (longitudinal), ksi	156.6	126.5	90.5
BUS (transverse), ksi	155.2	124.2	93.7
BYS (longitudinal), ksi	111.7	95.0	76.2
BYS (transverse), ksi	114.1	100.4	83.3

Properties	Temperature, F		
	RT	250	350
Shear(b)			
SUS (longitudinal), ksi	44.0	39.4	30.8
SUS (transverse), ksi	44.4	40.8	32.6
Impact			
V-notch Charpy, ft.lbs.			
(longitudinal)	5.8	U(c)	U
(transverse)	5.0	U	U
Fracture Toughness(d)			
K_{Ic} (longitudinal)	26.2	U	U
K_{Ic} (transverse)	32.1	U	U
Axial Fatigue (transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	70	60	54
10^5 cycles, ksi	50	39	33
10^7 cycles, ksi	43	31	26
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	50	48	45
10^5 cycles, ksi	20	18	16
10^7 cycles, ksi	17	12	11
Stress Corrosion(e)			
80% TYS, 1000 hr maximum	no cracks		
Coefficient of Thermal Expansion			
12.5×10^{-6} inch/inch/F (68 to 212 F)			
Density			
0.101 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of three tests in each direction.

(e) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

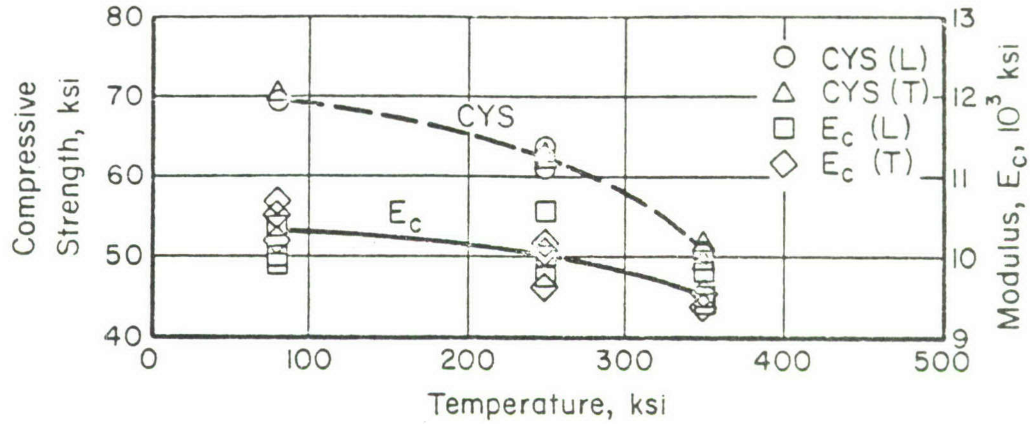


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

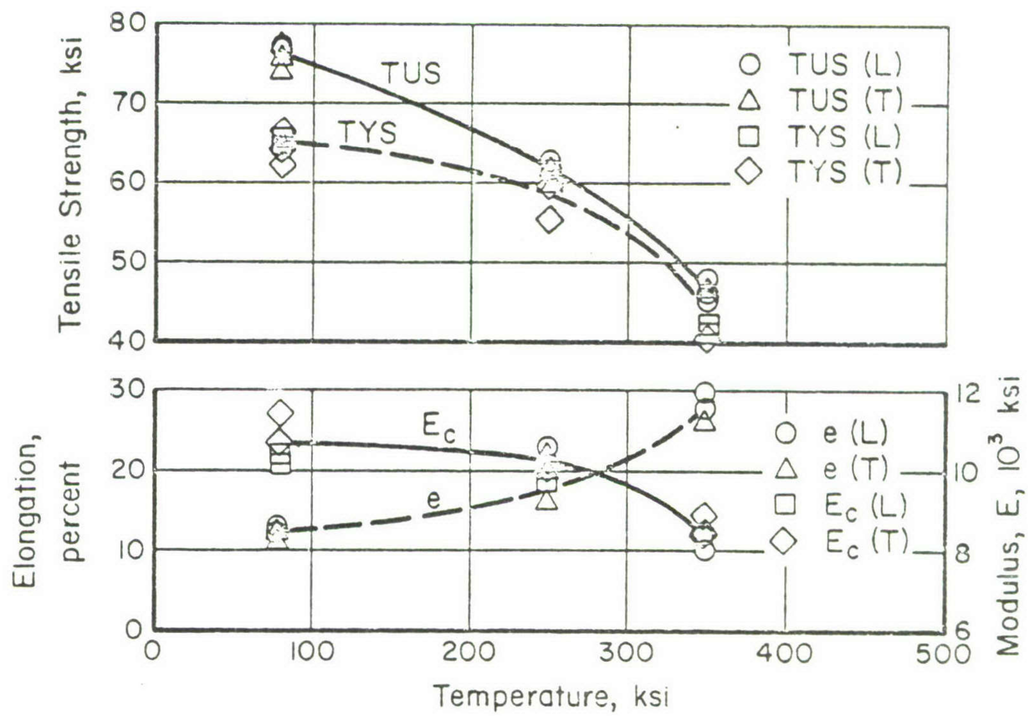


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

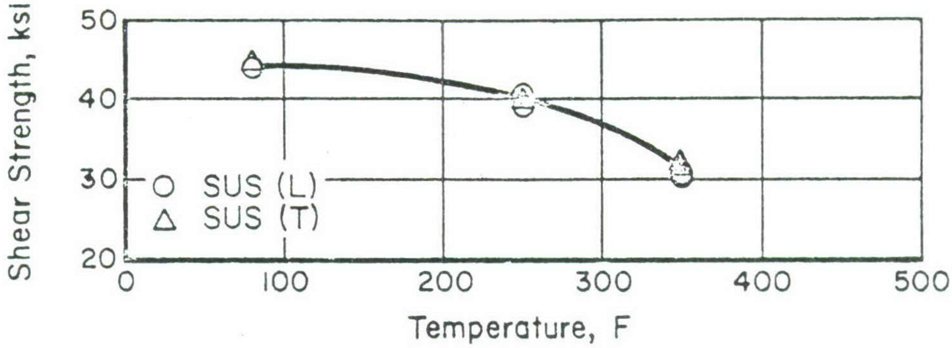


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

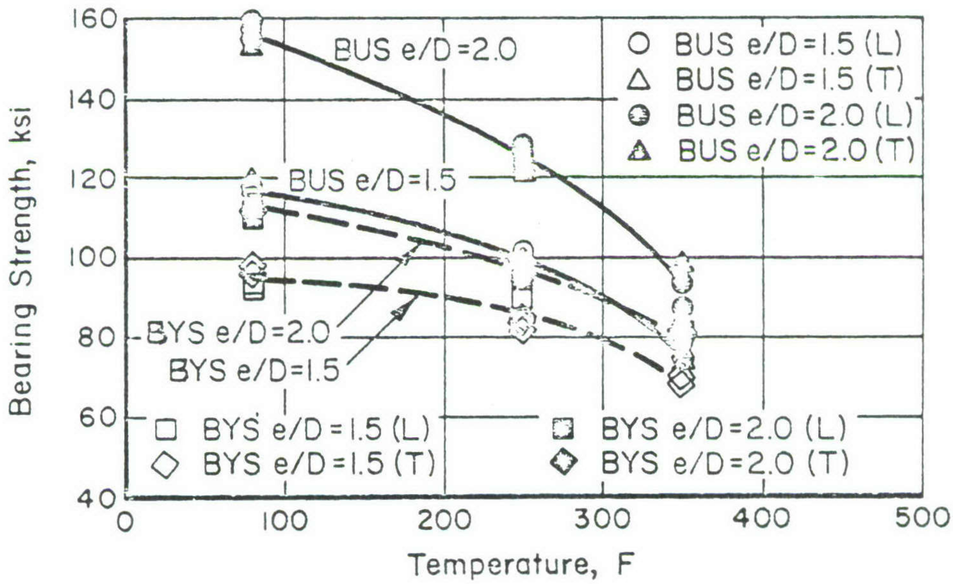


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

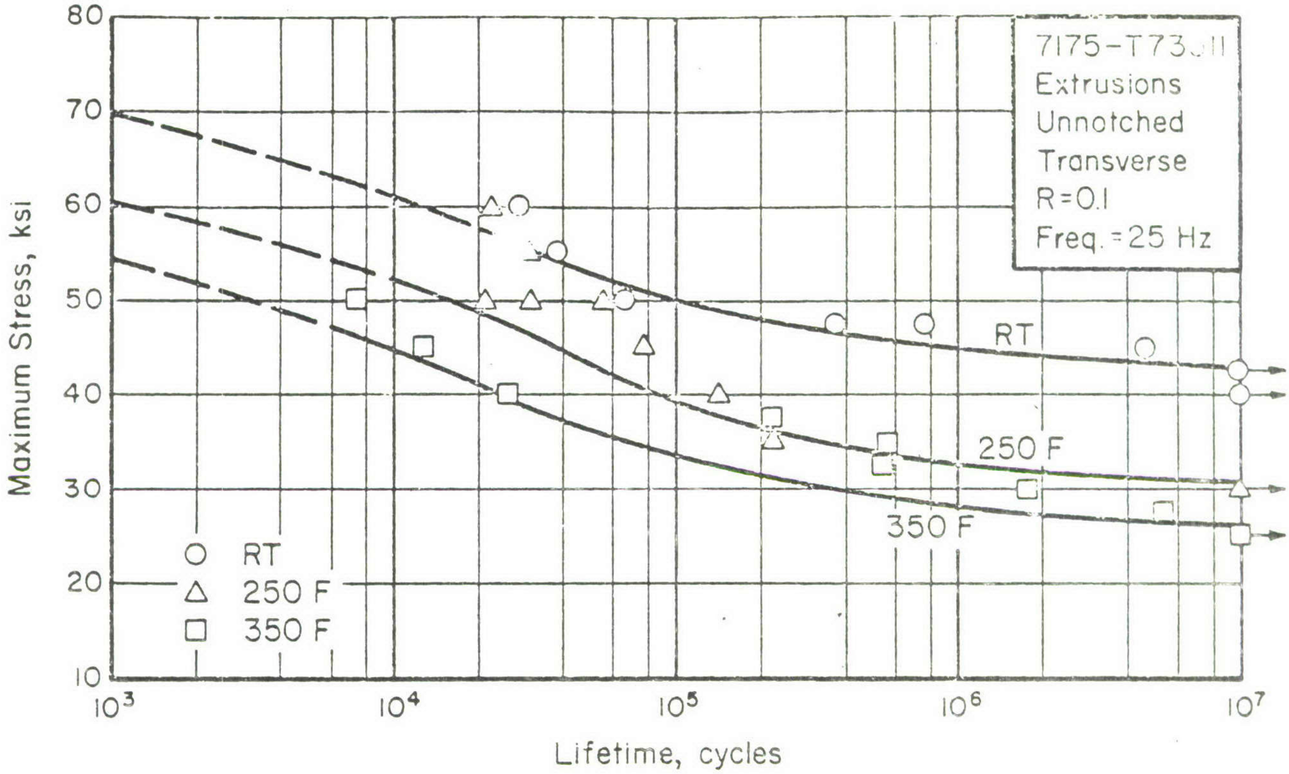


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

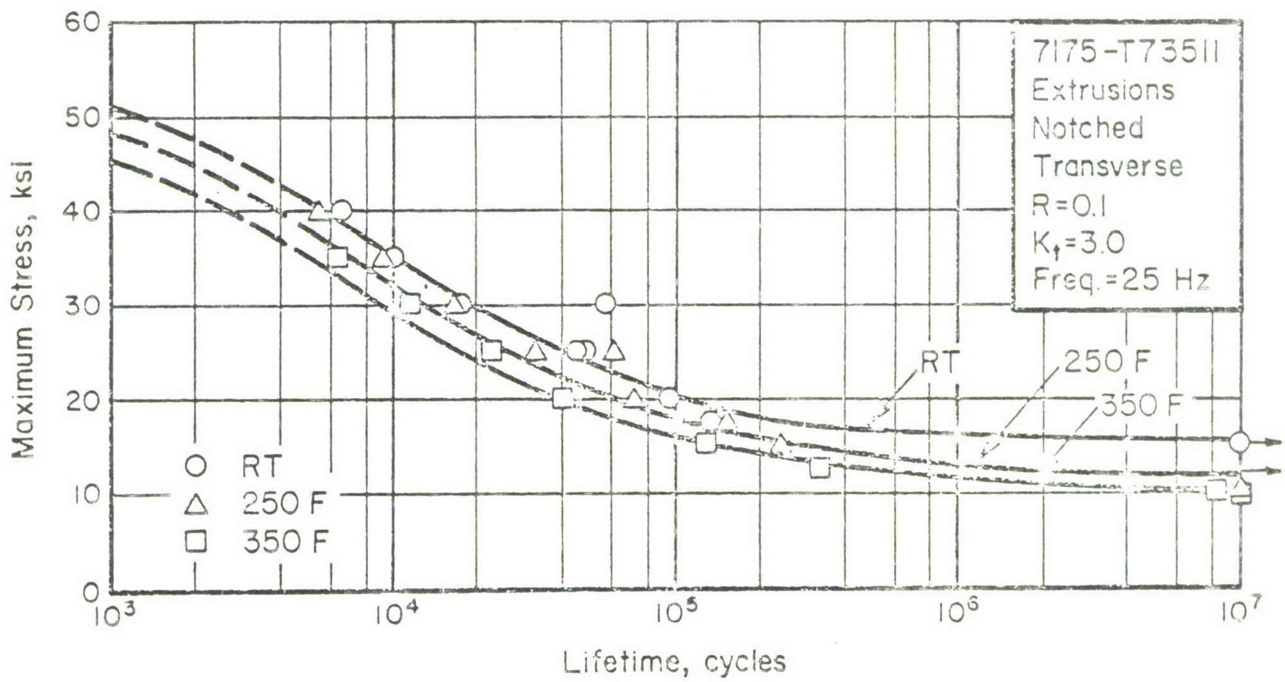


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7175-T73511 ALUMINUM ALLOY EXTRUSIONS

7050-T73 Aluminum Alloy

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was an extrusion from Alcoa about 3/4-inch thick by 24 inches wide by 24 inches long. It was identified as Section 303002. Alloy 7050 is produced within the following composition limits.

Chemical Composition	Percent
Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance.

Processing and Heat Treating

Specimens were tested in the as-received -T73 temper.

7050 Alloy Data[a]

Condition: -T73
Thickness: 3/4" approximate

Properties	Temperature, F RT	250	350
Tension			
TUS (longitudinal), ksi	77.4	62.7	50.3
TUS (transverse), ksi	75.8	60.5	49.0
TYS (longitudinal), ksi	67.5	61.4	49.6
TYS (transverse), ksi	66.1	58.6	48.6
e (longitudinal), percent in 2 in.	16	19	19
e (transverse), percent in 2 in.	13	16.7	15.3
RA (longitudinal), percent	45.4	53.5	63.4
RA (transverse), percent	34.0	48.2	56.7
E (longitudinal), 10^3 ksi	9.7	10.2	9.0
E (transverse), 10^3 ksi	9.7	9.7	9.4
Compression			
CYS (longitudinal), ksi	67.8	61.7	51.4
CYS (transverse), ksi	69.5	63.0	52.8
E_c (longitudinal), 10^3 ksi	10.3	10.1	8.6
E_c (transverse), 10^3 ksi	11.2	9.5	8.9
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	109.3	92.1	75.5
BUS (transverse), ksi	106.7	90.4	75.8
BYS (longitudinal), ksi	87.9	79.6	68.5
BYS (transverse), ksi	88.2	77.6	
e/D = 2.0			
BUS (longitudinal), ksi	149.9	116.8	94.6
BUS (transverse), ksi	146.4	116.3	92.8
BYS (longitudinal), ksi	106.0	93.5	77.5
BYS (transverse), ksi	108.9	95.6	75.6
Shear[b]			
SUS (longitudinal), ksi	46.1	36.5	29.8
SUS (transverse), ksi	44.5	35.0	28.9

7050 Alloy Data (Continued)

Properties	Temperature, F		
	RT	250	350
Impact			
V-notch Charpy, ft.lbs.[d]			
(longitudinal)	6.2	U[c]	U
(transverse)	6.2	U	U
Fracture Toughness			
K_{Ic} (longitudinal)	32.5	U	U
K_{Ic} (transverse)	33.2	U	U
Axial Fatigue (transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	75	60	49
10^5 cycles, ksi	56	51	43
10^7 cycles, ksi	44	38	30
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	55	50	47
10^5 cycles, ksi	20	17	13
10^7 cycles, ksi	11	10	10
Stress Corrosion[e]			
80 percent TYS, 1000 hr. max.	No cracks		
Coefficient of Thermal Expansion			
12.8×10^{-6} in/in/F (68 - 212 F)			
Density			
0.102 lb/in^3			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.
(b) Double-shear pin-type specimen; average of three tests in each direction.
(c) U, unavailable; NA, not applicable.
(d) Average of three tests in each direction.
(e) Alternate immersion, 3½ percent NaCl.

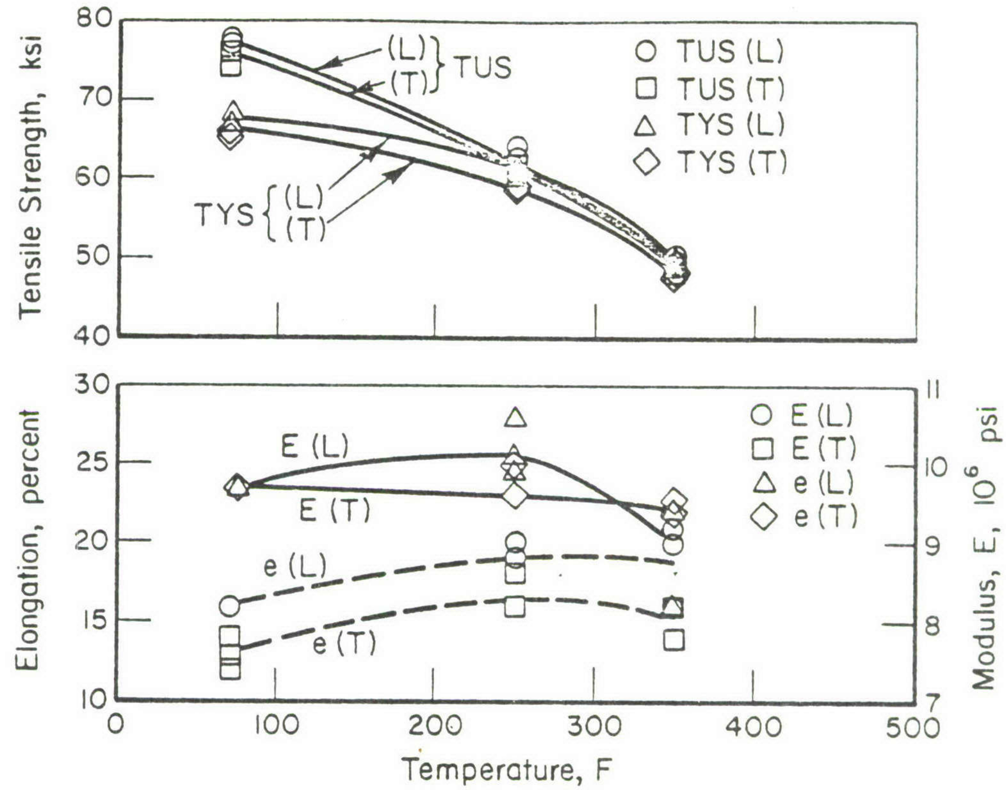


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

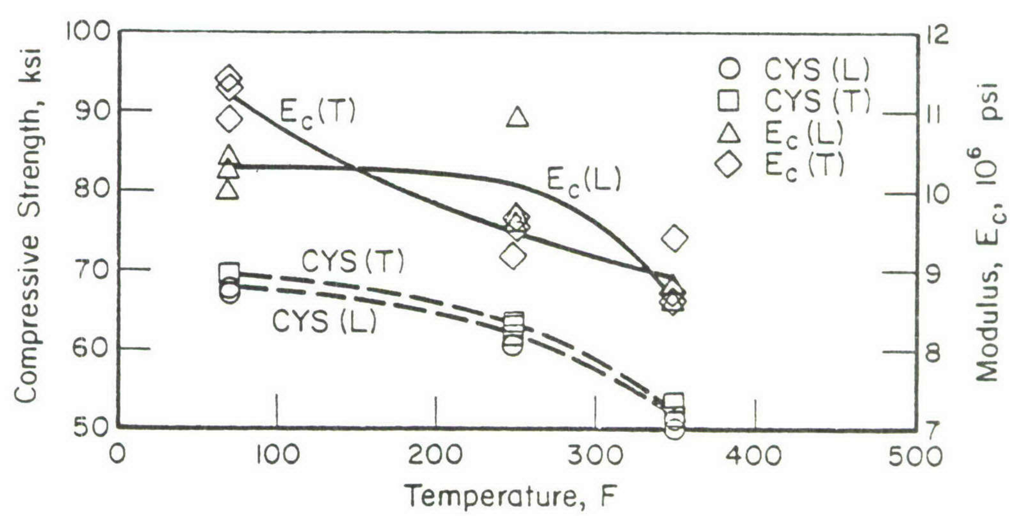


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

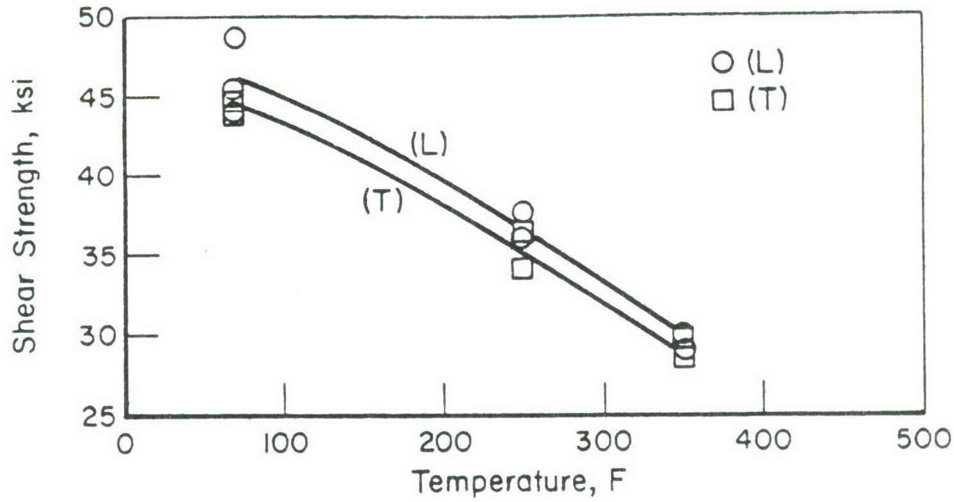


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

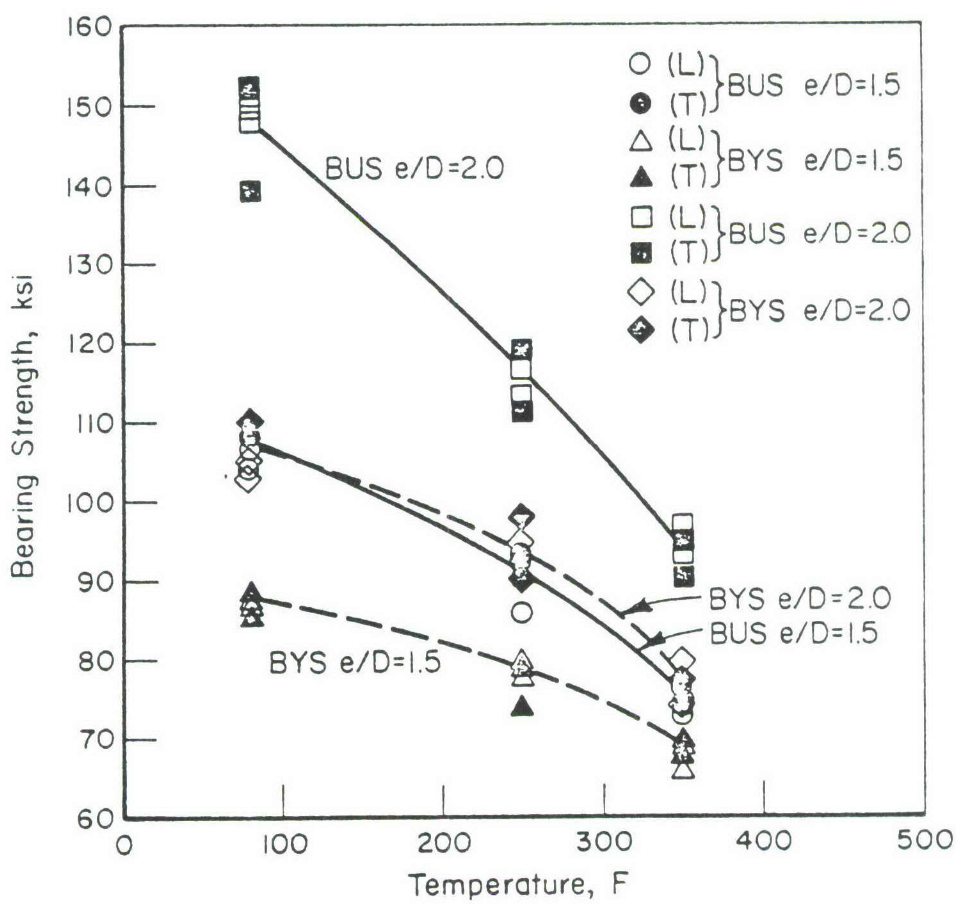


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF 7050-T73 ALUMINUM ALLOY EXTRUSIONS

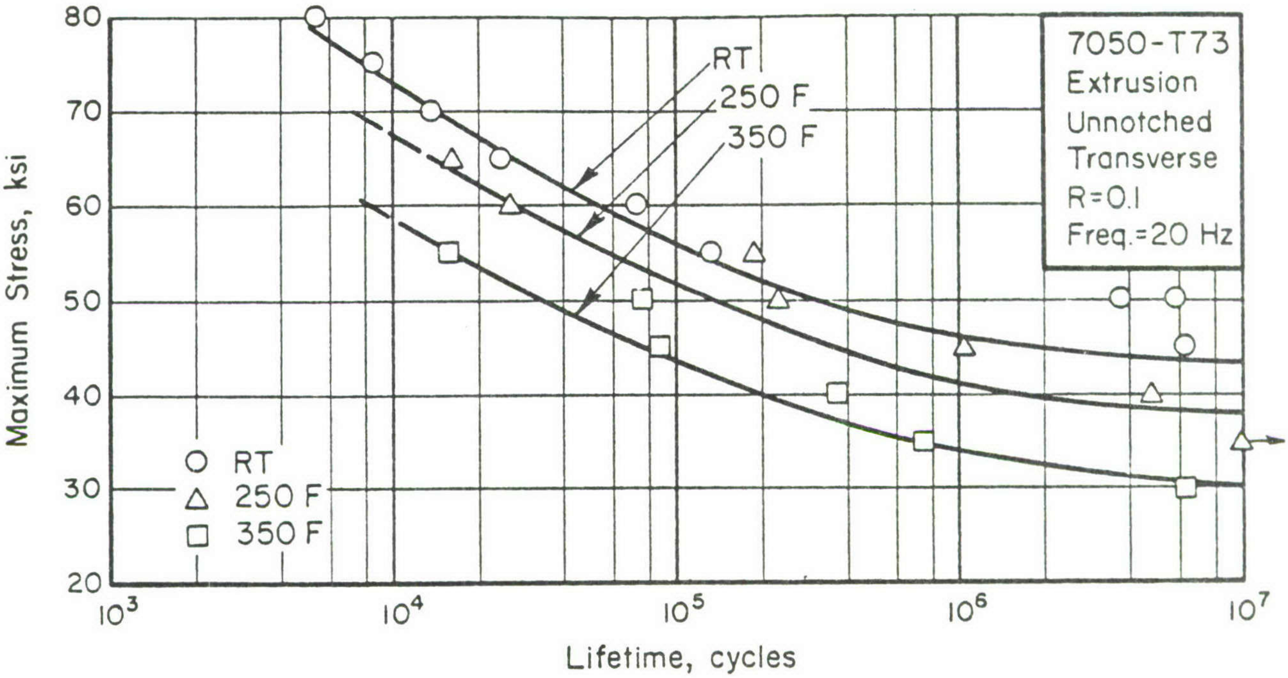


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73 ALUMINUM ALLOY EXTRUSIONS

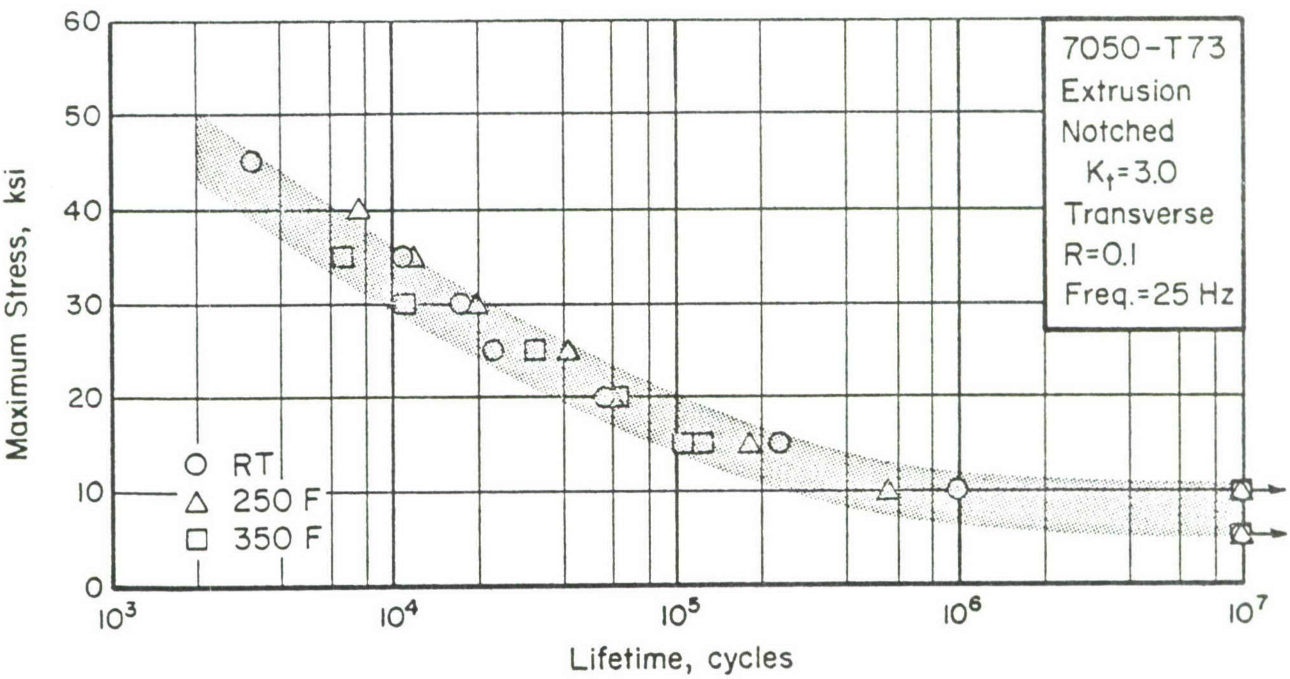


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 7050-T73 ALUMINUM ALLOY EXTRUSIONS

Ti-6Al-4V PM Product

Material Description

The material used for this evaluation was Ti-6Al-4V pressed and vacuum sintered to 94 percent minimum density. It was supplied by Dynamet Technology and produced as part of current manufacturing production run for various parts, it varied in cross section and length from 2 inches x 1 inch x 6 inches to smaller sizes.

Processing and Heat Treating

The material was evaluated in the as-received condition as described above. Specimens were selected from various section sizes of the total of 90 inches (12 pieces) of material.

Ti-6Al-4V PM Alloy Data[a]

Condition: Pressed and Sintered
Thickness: Various

Properties	Temperature, F RT	400	800
Tension			
TUS (longitudinal), ksi	106.1	78.6	62.0
TYS (longitudinal), ksi	92.4	67.3	45.7
e (longitudinal), percent in 1 in.	5.0	4.5	8.0
RA (longitudinal), percent	4.9	7.9	8.5
E (longitudinal), 10^3 ksi	15.3	13.5	12.0
Compression			
CYS (longitudinal), ksi	97.7	70.7	50.0
E_c (longitudinal), 10^3 ksi	14.5	12.6	11.3
Bearing			
e/D = 1.5			
BUS, ksi	176.8	139.3	114.3
BYS, ksi	151.3	117.8	94.2
e/D = 2.0			
BUS, ksi	225.5	169.1	141.8
BYS, ksi	173.0	134.1	105.9
Shear[b]			
SUS (longitudinal), ksi	72.6	59.8	45.7
Impact			
V-notch Charpy, ft.lbs. (longitudinal)	13.5[d]	U[c]	U
Fracture Toughness[e]			

Ti-6Al-4V PM Alloy Data (Continued)

Properties	Temperature, F		
	RT	400	800
Axial Fatigue (transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	100	80	80
10^5 cycles, ksi	47	40	40
10^7 cycles, ksi	20	30	30
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	50	46	40
10^5 cycles, ksi	26	34	25
10^7 cycles, ksi	12	22	20
Stress Corrosion			
80% TYS, 1000 hrs. maximum	no cracks[f]		
Coefficient of Thermal Expansion			
6.2×10^{-6} in./in./F (70-800 F)			
Density			
0.151 lb./in.^{3}			

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen; average of three tests in each direction.

(c) U, unavailable; NA, not applicable.

(d) Average of five tests.

(e) Material of insufficient size for fracture tests.

(f) Alternate immersion, 3½% NaCl.

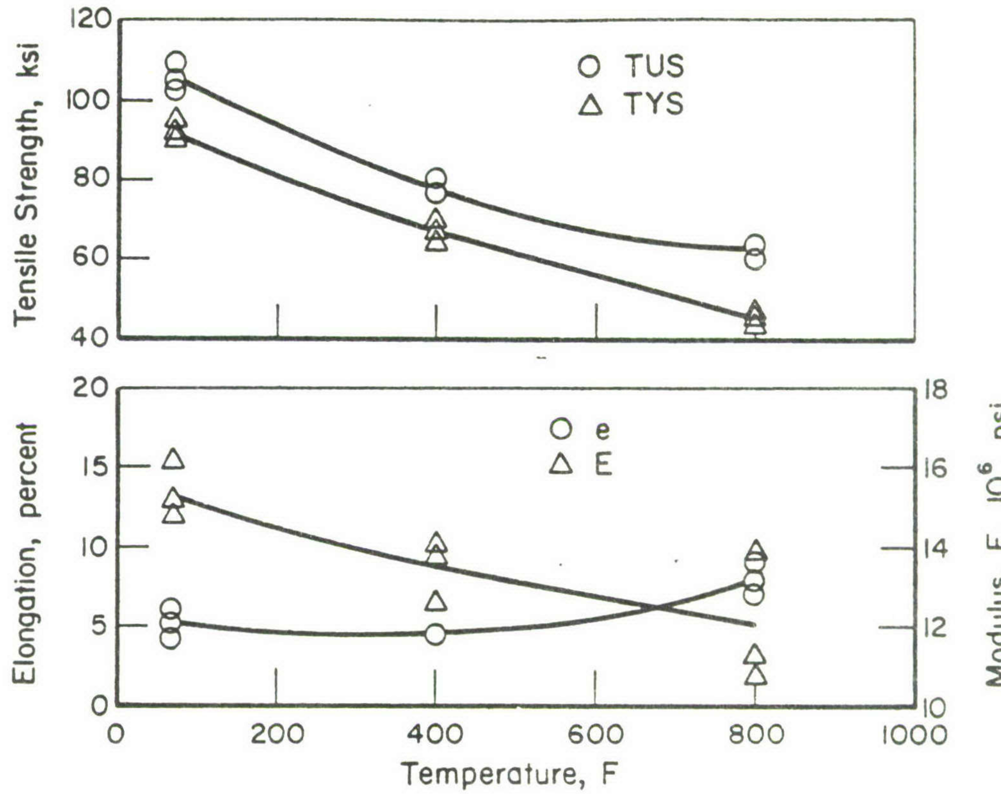


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V PM PRODUCT

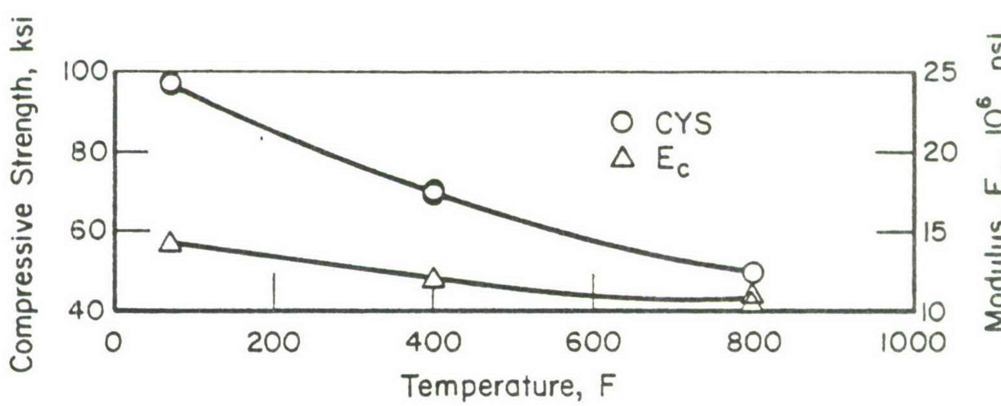


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V PM PRODUCT

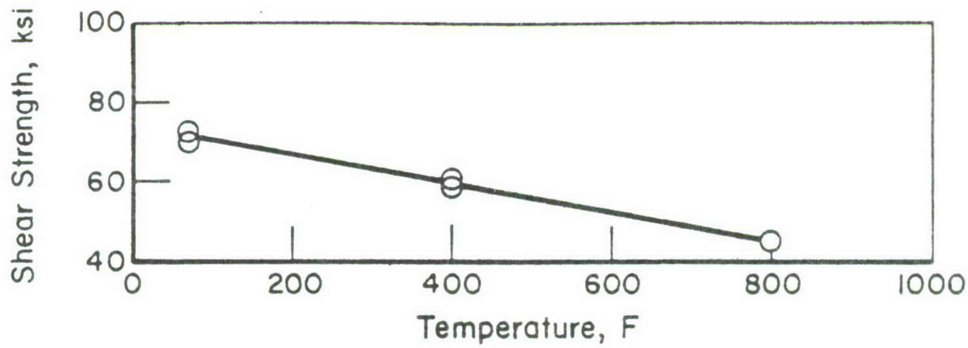


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF Ti-6Al-4V PM PRODUCT

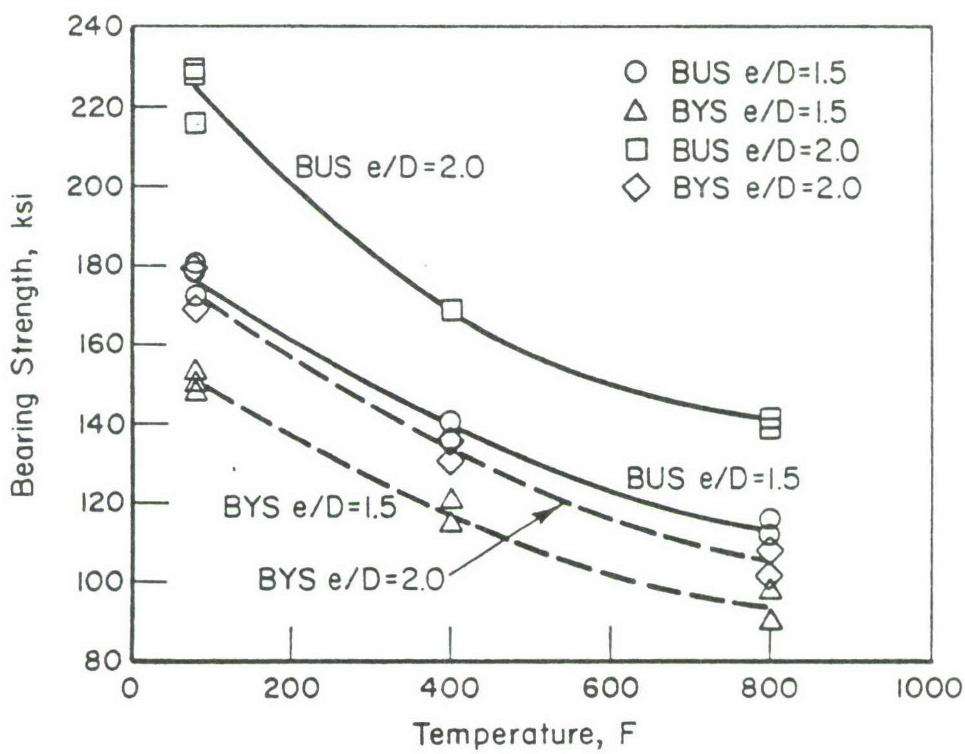


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF Ti-6Al-4V PM PRODUCT

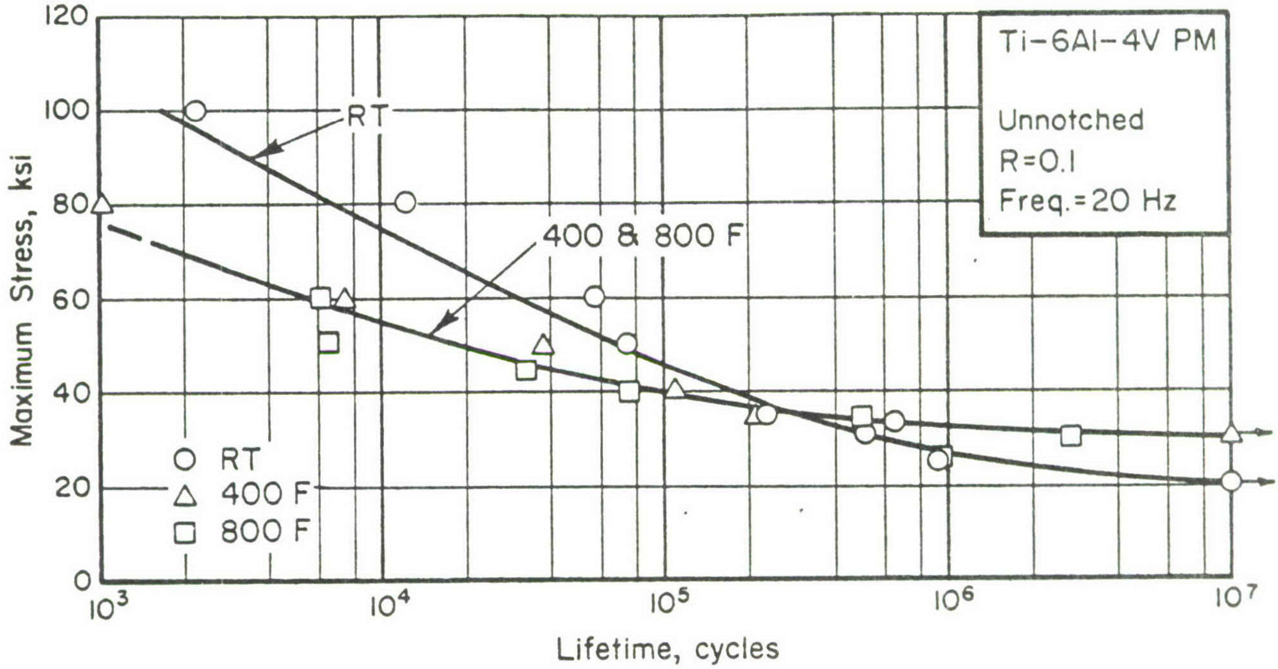


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED Ti-6Al-4V PM PRODUCT

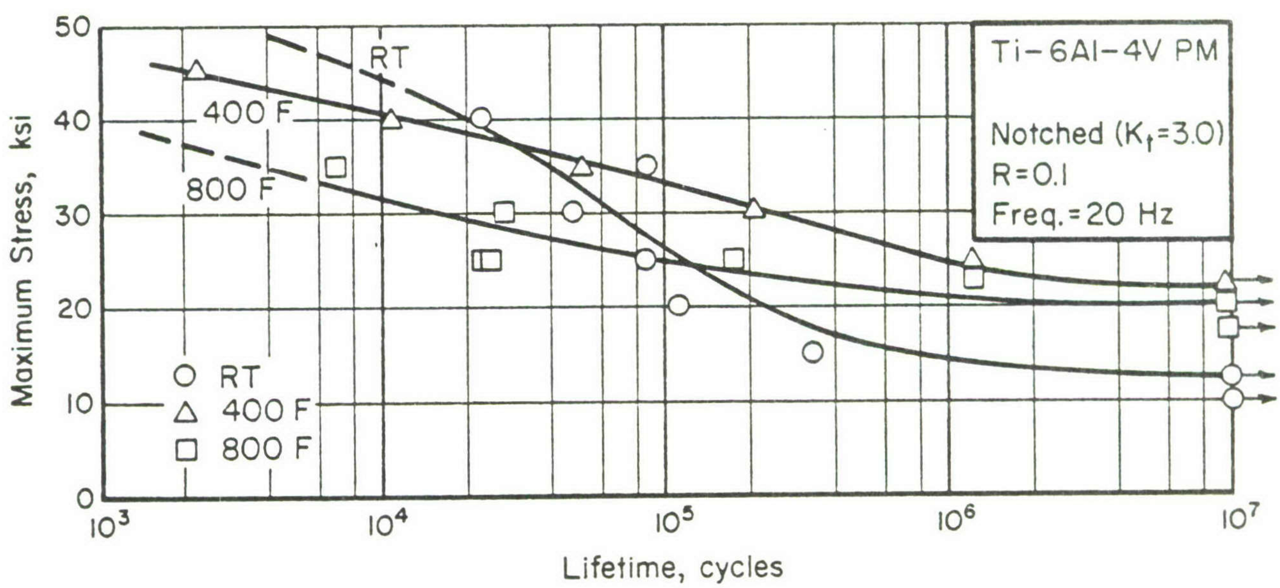


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) Ti-6Al-4V PM PRODUCT

Superplastically Formed Ti-6Al-4V Alloy

Material Description

The material used for this evaluation was Ti-6Al-4V superplastically formed as described in AFML-TR-75-62, "Superplastic Forming of Titanium Structures". Two nacelle forward center beam frames resulting from the program described in AFML-TR-75-62 were supplied by the Air Force. Extensive information regarding the material, forming processes, and material properties may be found in the AFML Technical Report.

Processing and Heat Treating

The area of flat material from which to section specimens was limited. Also it was discovered that the thickness varied in the available flat areas and it was necessary to surface grind the specimens obtained. Only tensile, compression, and fatigue specimens were available from the material.

Ti-6Al-4V Alloy Data[a]

Condition: Superplastically Formed
Thickness: 0.040 - 0.080

Properties	Temperature, F RT	400	800
Tension			
TUS (transverse), ksi	139.9	110.7	92.8
TYS (transverse), ksi	127.3	91.7	71.1
e (transverse), percent in 1 in.	15.5	11.5	10.0
E (transverse), 10^3 ksi	17.7	15.0	15.9
Compression			
CYS (transverse), ksi	122.7	105.7	70.3
E_c (transverse), 10^3 ksi	17.4	14.6	14.3
Axial Fatigue (Transverse)			
Unnotched, R = 0.1			
10^3 cycles, ksi	100	95	
10^5 cycles, ksi	57	40	
10^7 cycles, ksi	(38)	(20)	
Notched, K_t = 3.0, R = 0.1			
10^3 cycles, ksi	77	77	
10^5 cycles, ksi	32	32	
10^7 cycles, ksi	15	20	

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

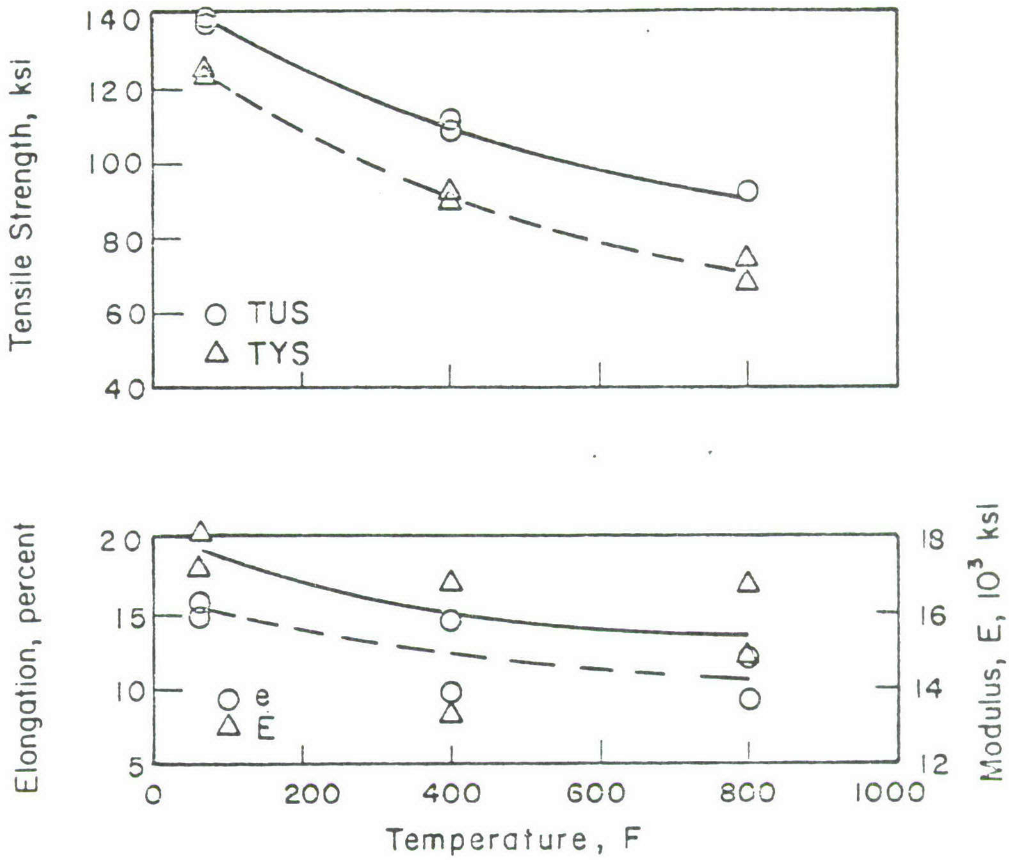


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

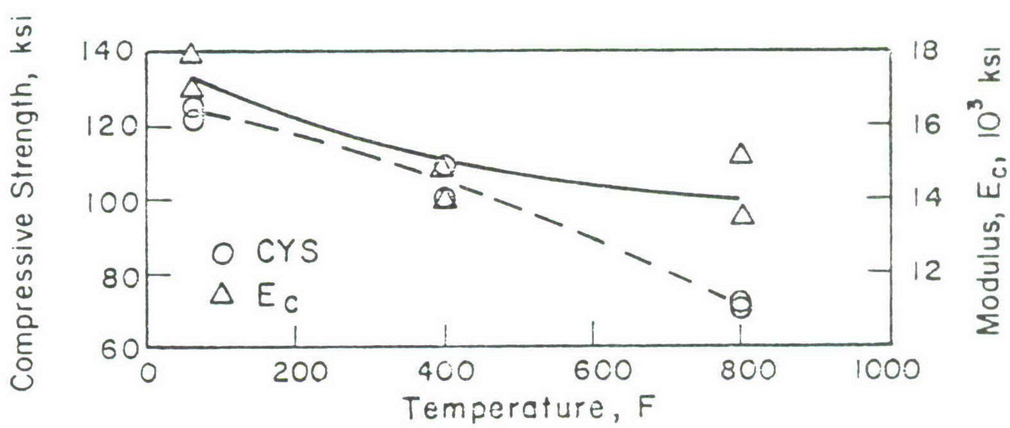


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

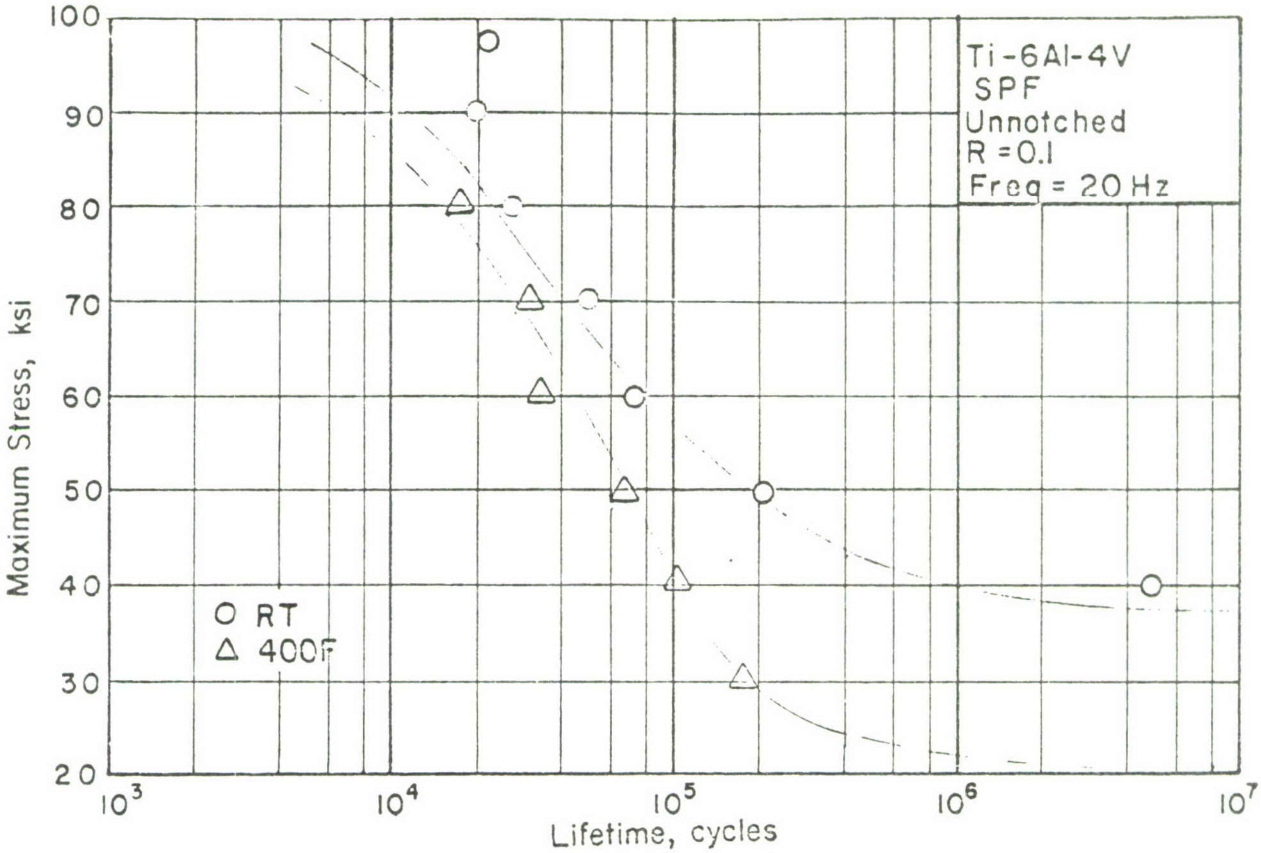


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

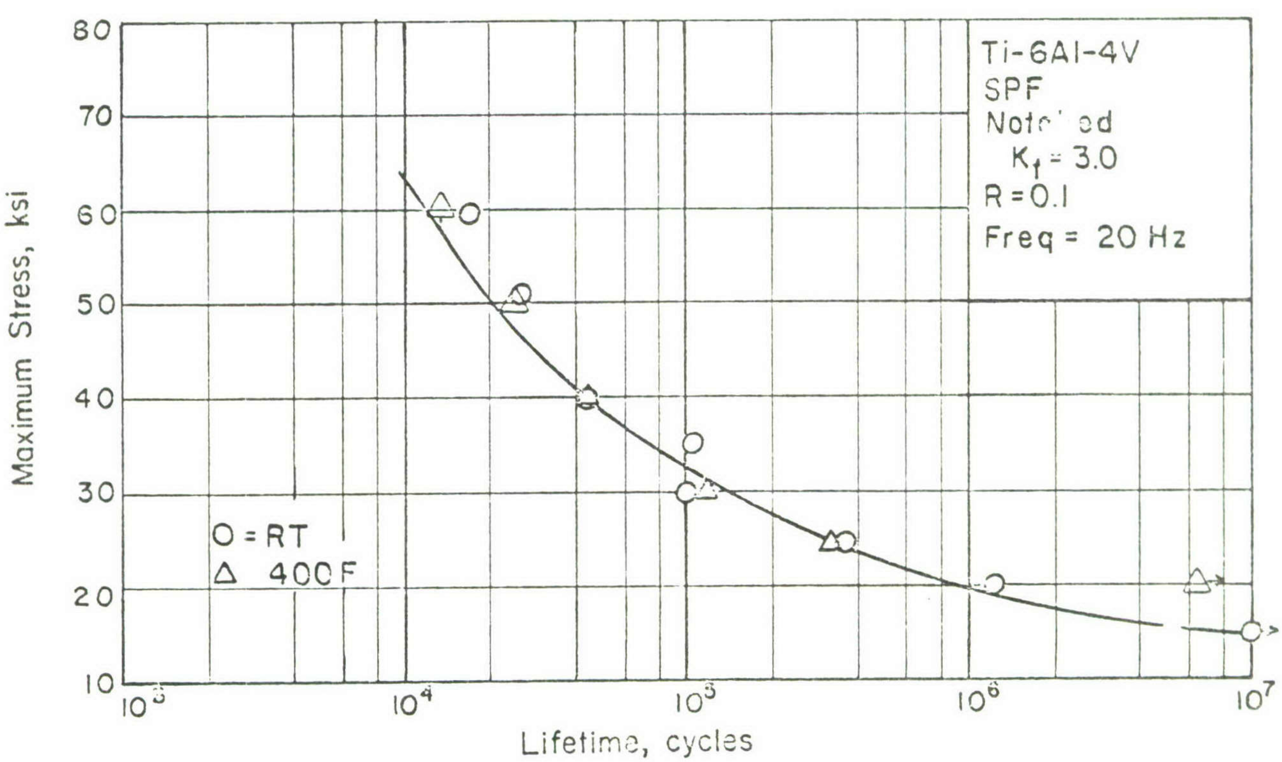


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SUPERPLASTICALLY FORMED Ti-6Al-4V ALLOY

Ti-10V-2Fe-3Al Alloy

Material Description

This alloy is a recent development of TIMET, a division of Titanium Metals Corporation of America. The alloy, metallurgically near-beta, is a high fracture toughness composition and is capable of attaining a variety of strength levels, depending on the selection of heat treatment. In the solution-treated and aged condition, the alloy shows creep-stability characteristics similar to the alpha-beta alloys at 600 F. A major advantage, other than toughness, is its excellent forgeability. It moves readily at temperatures below those required for Ti-6Al-4V.

TIMET believes the alloy should be considered for applications up to 600 F where medium to high strength and high toughness are required in sections up to five inches thick.

The nominal composition of Ti-10V-2Fe-3Al is:

Chemical Composition	Percent
Al	2.6 - 3.4
V	9.0 - 11.0
Fe	1.8 - 2.2
O	0.16 max
C	0.05 max
N	0.05 max
H	0.015 max
Others, Each	0.10 max
Others, Total	0.30 max

The material used for this evaluation was 3-inch round bar from TIMET heat P-1452.

Processing and Heat Treating

The material was heat treated as follows: 1 hour at 1400 F, furnace cooled plus 8 hours at 1050 F, air cooled. This is an intermediate strength, STOA condition. All specimens were sectioned in the longitudinal direction from the bar.

Ti-10V-2Fe-3Al Alloy Data[a]

Condition: STOA
Thickness: 3" Round Bar

Properties	Temperature, F RT	400	800
Tension			
TUS (longitudinal), ksi	141.5	119.8	97.2
TYS (longitudinal), ksi	137.7	106.4	78.9
e (longitudinal), percent in 1 in.	18.3	21.3	22.3
RA (longitudinal), percent	62.5	65.6	79.5
E (longitudinal), 10^3 ksi	14.7	14.0	11.4
Compression			
CYS (longitudinal), ksi	139.6	107.4	80.1
E_c (longitudinal), 10^3 ksi	15.4	14.3	12.6
Bearing			
e/D = 1.5			
BUS (longitudinal), ksi	239.3	198.7	153.0
BYS (longitudinal), ksi	190.0	159.0	132.3
e/D = 2.0			
BUS (longitudinal), ksi	290.3	258.3	195.0
BYS (longitudinal), ksi	226.3	192.0	153.3
Shear[b]			
SUS (longitudinal), ksi	97.2	82.3	67.0
Impact[d]			
V-notch Charpy, ft.lbs.			
(longitudinal)	28.8	U[c]	U
(transverse)	19.0	U	U
Fracture Toughness			
K_{Ic} (longitudinal)	77.4[e]	NA	NA

(Continued)

	Temperature, F				
Properties	RT		400		800
Axial Fatigue (Longitudinal)					
Unnotched, R = 0.1					
10^3 cycles, ksi	150		120		110
10^5 cycles, ksi	130		110		75
10^7 cycles, ksi	110		102		65
Notched, K_t = 3.0, R = 0.1					
10^3 cycles, ksi	80		80		80
10^5 cycles, ksi	21		21		21
10^7 cycles, ksi	15		15		15
Creep (longitudinal)		700 F		900 F	
0.2% plastic deformation, 100 hr, ksi		25		13	
0.2% plastic deformation, 1000 hr, ksi		3.2		1.2	
Stress Rupture (Longitudinal)					
Rupture, 100 hr, ksi		91		85	
Rupture, 1000 hr, ksi		27		14	
Stress Corrosion					
80% TYS, 1000 hr maximum	No Cracks (f)			U	
Coefficient of Thermal Expansion					
5.4×10^{-6} in./in./F (RT to 800 F)					
Density					
0.168 lb./in.^{3}					

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.
(b) Double-shear pin-type specimen; average of three tests in each direction.
(c) U, unavailable; NA, not applicable.
(d) Average of three tests.
(e) Average of four tests.
(f) Alternate immersion, 3.5% NaCl.

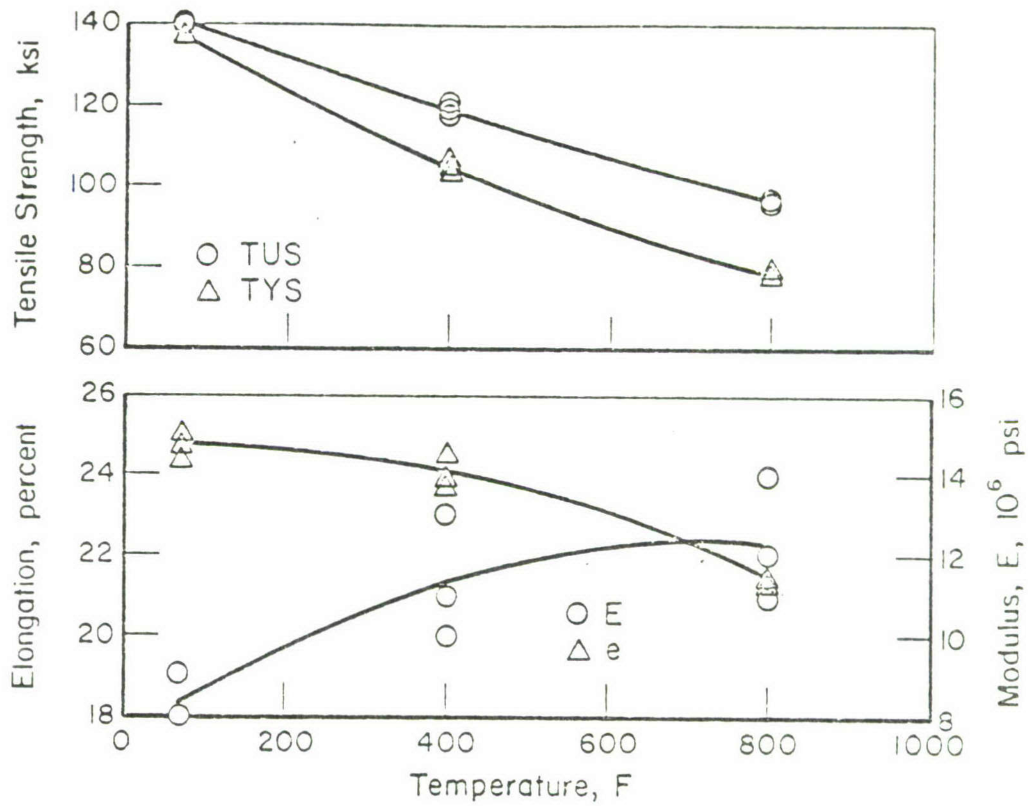


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

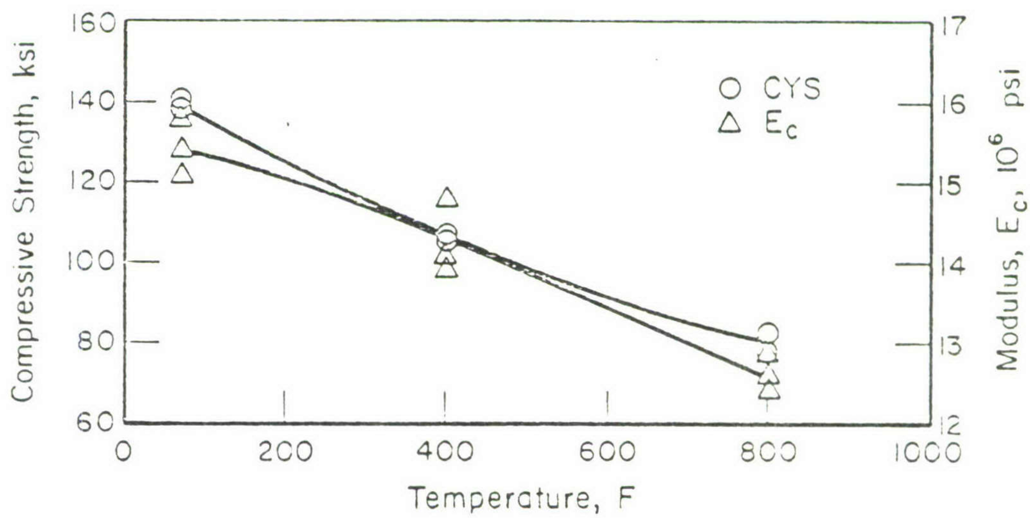


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

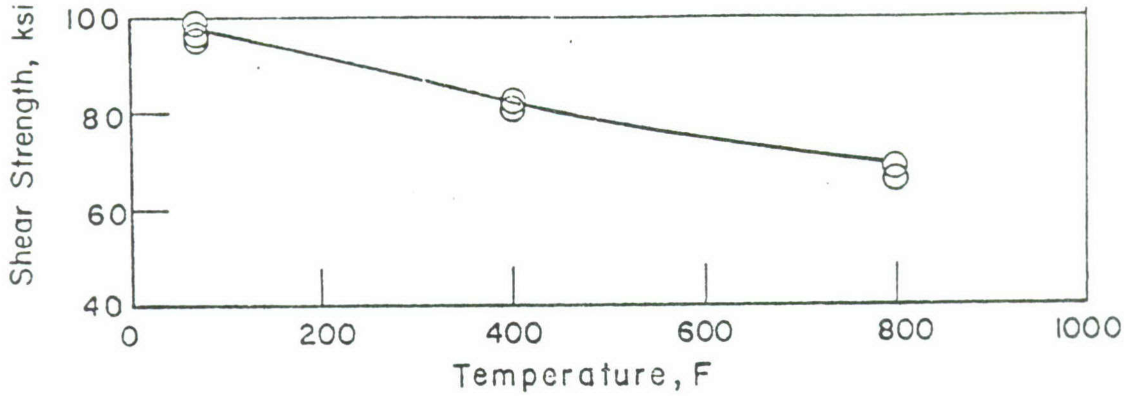


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

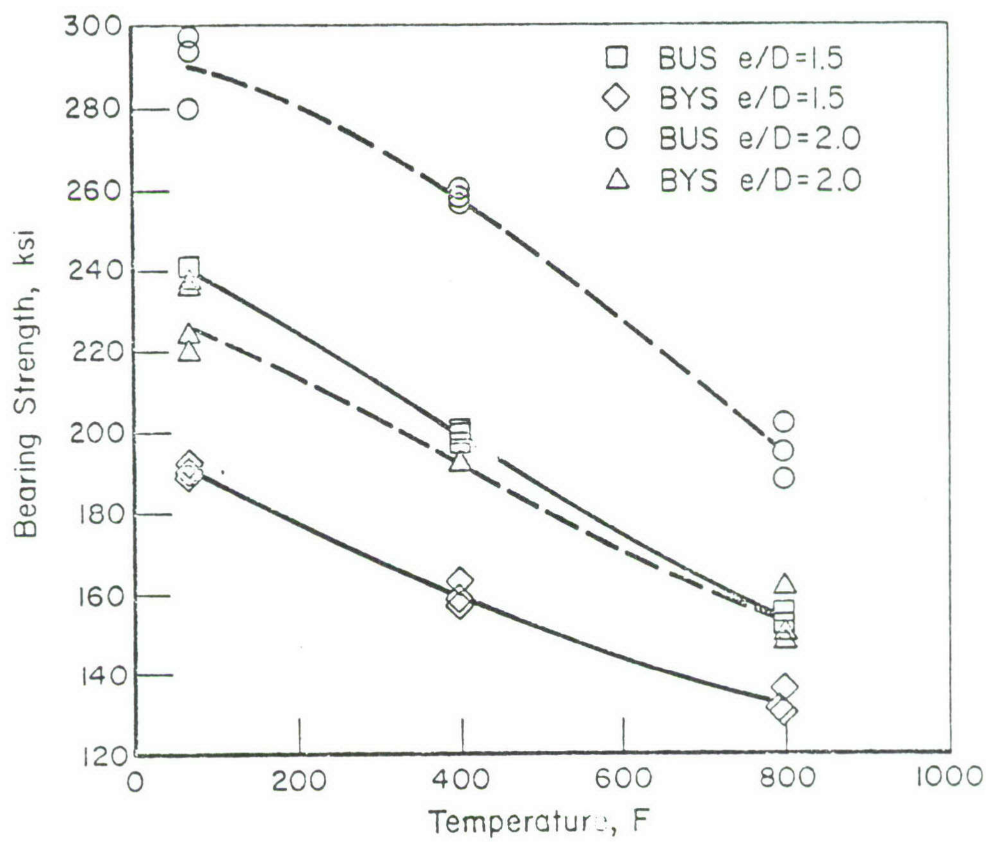


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF STOA Ti-10V-2Fe-3Al ROUND BAR

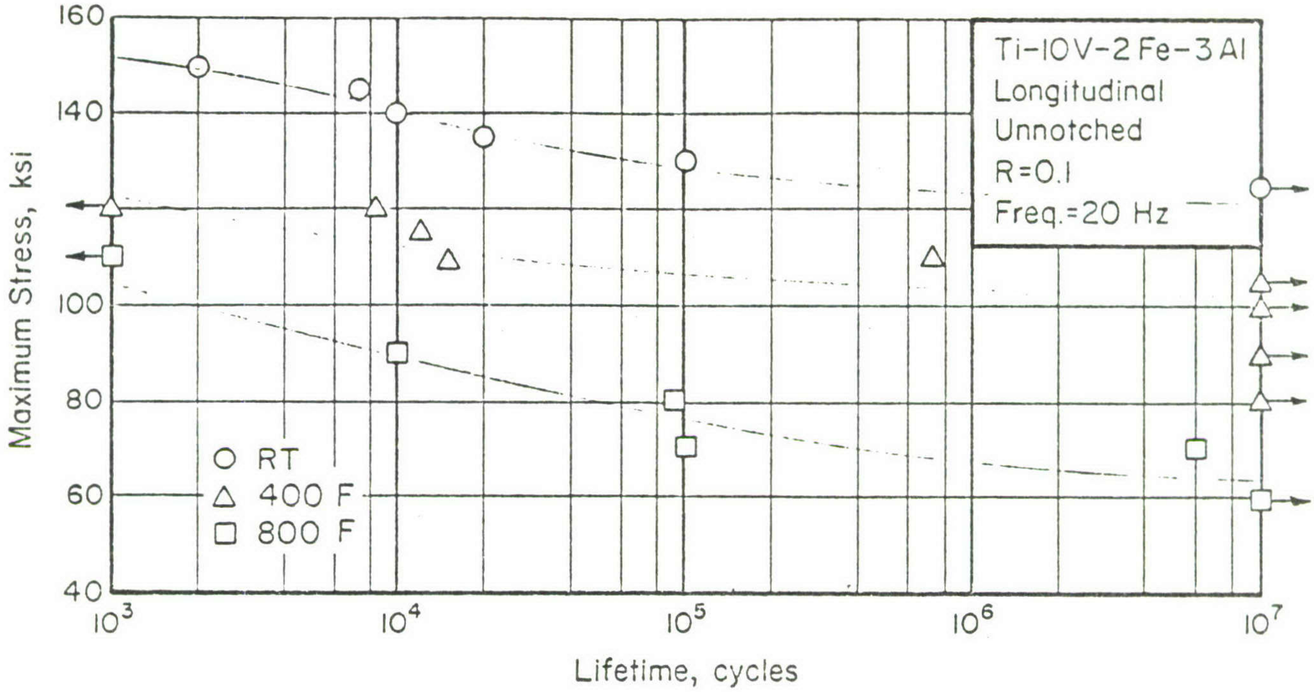


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED STOA Ti-10V-2Fe-3Al ROUND BAR

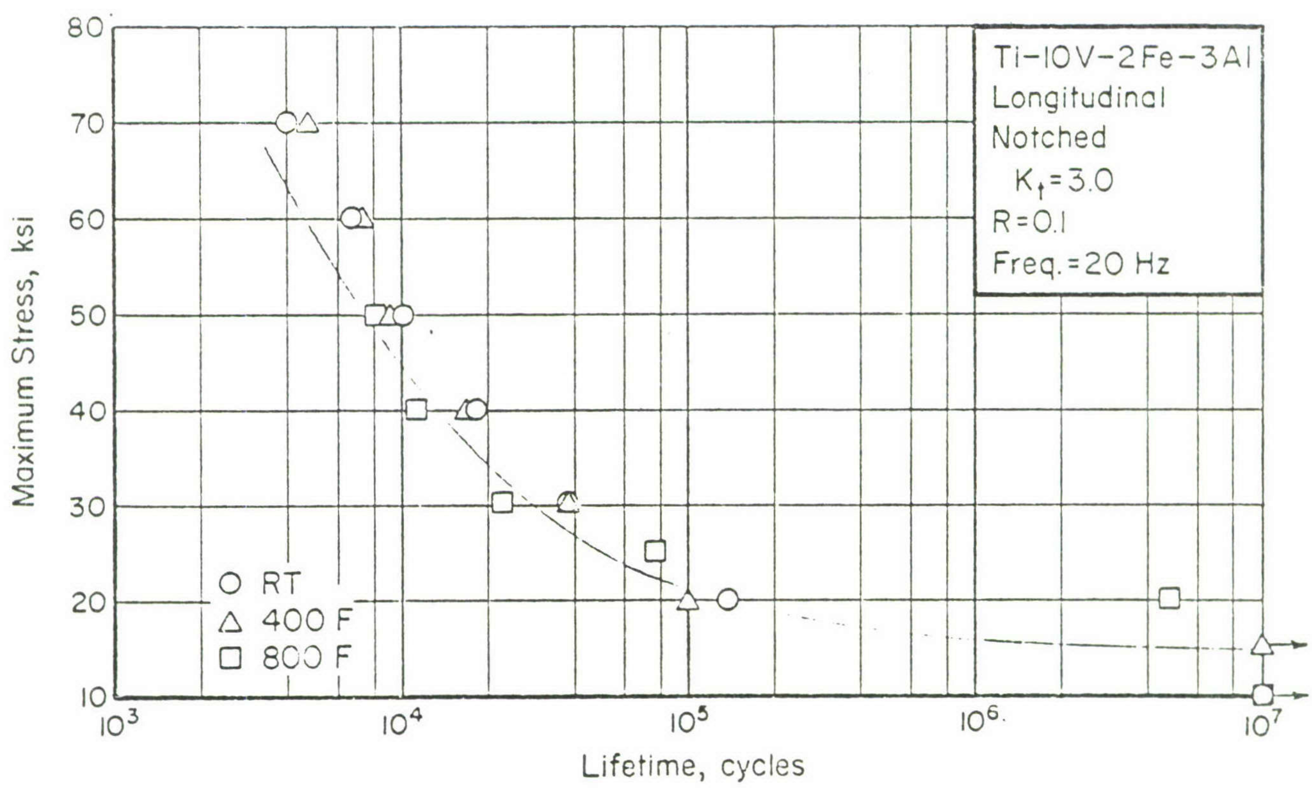


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) STOA Ti-10V-2Fe-3Al ROUND BAR

4330M Data[a]

Condition: Heat Treated
Thickness: Varying thickness forging

Properties	Room Temperature
Tension	
TUS (longitudinal), ksi	244.4
TUS (transverse), ksi	242.4
TYS (longitudinal), ksi	203.8
TYS (transverse), ksi	202.4
e (longitudinal), percent in 1 inch	12.3
e (transverse), percent in 1 inch	12.0
RA (longitudinal), percent	50.0
RA (transverse), percent	48.4
E (longitudinal), 10^3 ksi	28.9
E (transverse), 10^3 ksi	29.0
Compression	
CYS (longitudinal), ksi	221.4
CYS (transverse), ksi	221.9
E_c (longitudinal), 10^3 ksi	29.3
E_c (transverse), 10^3 ksi	29.6
Shear[b]	
SUS (longitudinal), ksi	159.6
SUS (transverse), ksi	157.1
Impact, Charpy V-Notch	
Longitudinal, ft. lbs.	15.3
Transverse, ft. lbs.	14.2

Properties	Room Temperature
Fracture Toughness[c]	
K_{Ic}, ksi$\sqrt{in.}$ (T-ST)	76.3
Axial Fatigue (Transverse)[d]	
Unnotched, R=0.1	
10^3 cycles, ksi	236
10^5 cycles, ksi	196
10^7 cycles, ksi	175
Notched, K_t = 3.0, R=0.1	
10^3 cycles, ksi	184
10^5 cycles, ksi	70
10^7 cycles, ksi	65
Density	
0.283 lb./in.^{3}	

(a) Values given are average of triplicate tests conducted at Battelle Columbus under the subject contract unless otherwise indicated. Values for fatigue are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen.

(c) Compact tension-type specimen.

(d) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

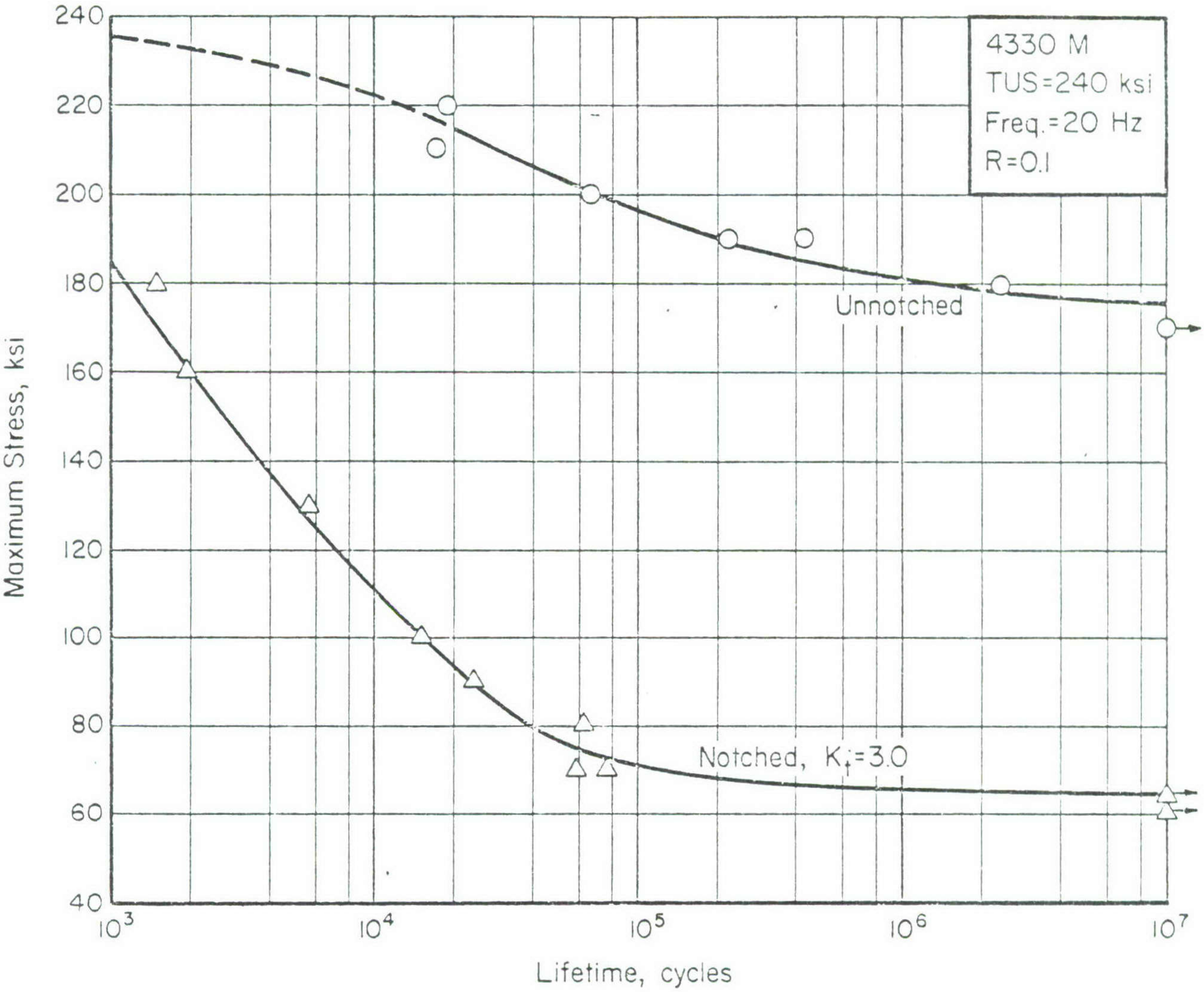


FIGURE 1. AXIAL-LOAD-FATIGUE BEHAVIOR OF 4330M AT ROOM TEMPERATURE

Custom 450 Alloy

Material Description

Custom 450 is a multiple-strength heat-treatable stainless steel. The alloy was developed by Carpenter to meet the need for an alloy with the corrosion resistance of Type 304 stainless and with an annealed strength close to 100 ksi (689.5 MPa).

The Custom 450 strip used in this evaluation was 0.040-inch (1.016 mm) thick, with Carpenter Heat Number 825980. Strip form was chosen due to availability. The alloy was supplied in the solution-annealed state. The composition was as follows:

Chemical Composition	Percent
C	.028
Mn	.33
Si	.42
P	.026
S	.001
Cr	14.95
Ni	6.44
Mo	.79
Cu	1.50
Cb	.70

Processing and Heat Treating

Specimens were heat treated to the H 900 condition. This consists of aging at 900 F (482°C) for 4 (four) hours and air cooled. This heat treatment and the elevated temperatures chosen for evaluation were selected to reinforce data approved for use in MIL-HDBK-5.*

* Approved at the 51st Meeting, Item No. 75-23.

Custom 450 Stainless Steel[a]

Condition: H 900
Thickness: 0.040 in. (1.016 mm)

Properties	Temperature, F (K)					
	RT	(RT)	400	(477)	800	(700)
Tension						
TUS, L, ksi (MPa)	195.2	(1345.9)	170.6	(1176.3)	148.6	(1024.6)
TUS, T, ksi (MPa)	198.6	(1369.3)	172.6	(1190.1)	150.8	(1039.8)
TYS, L, ksi (MPa)	191.0	(1316.9)	162.9	(1123.2)	133.7	(921.9)
TYS, T, ksi (MPa)	194.0	(1337.6)	164.9	(1137.0)	135.5	(934.3)
e, L, percent in 2 in. (50.8 mm)	6.8	(6.8)	5.0	(5.0)	6.0	(6.0)
e, T, percent in 2 in. (50.8 mm)	6.2	(6.2)	5.0	(5.0)	5.8	(5.8)
E, L, 10^3 ksi (GPa)	30.3	(208.8)	26.3	(181.3)	24.1	(166.2)
E, T, 10^3 ksi (GPa)	30.2	(208.2)	27.2	(187.3)	24.3	(167.8)
Compression						
CYS, L, ksi (MPa)	204.6	(1410.7)	178.9	(1233.5)	150.4	(1037.0)
CYS, T, ksi (MPa)	208.8	(1439.7)	180.5	(1244.5)	151.5	(1044.6)
E_c, L, 10^3 ksi (GPa)	31.9	(220.0)	29.1	(200.6)	28.0	(193.1)
E_c, T, 10^3 ksi (GPa)	32.6	(224.8)	31.4	(216.5)	28.9	(199.3)
Shear						
SUS, L, ksi (MPa)	127.6	(879.8)	109.4	(754.3)	91.8	(633.0)
SUS, T, ksi (MPa)	126.4	(871.5)	107.6	(741.9)	91.7	(632.3)
Bearing						
e/D = 1.5						
BUS, L, ksi (MPa)	309.1	(2131.2)	262.1	(1807.2)	224.3	(1546.5)
BUS, T, ksi (MPa)	303.5	(2092.6)	258.5	(1782.4)	219.5	(1513.4)
BYS, L, ksi (MPa)	258.8	(1784.4)	235.9	(1626.5)	203.1	(1400.4)
BYS, T, ksi (MPa)	259.7	(1790.6)	233.8	(1612.1)	200.6	(1383.1)
e/D = 2.0						
BUS, L, ksi (MPa)	348.9	(2405.7)	323.0	(2227.1)	280.0	(1930.6)
BUS, T, ksi (MPa)	367.9	(2536.7)	319.0	(2199.5)	298.8	(2060.2)
BYS, L, ksi (MPa)	303.6	(2093.3)	276.2	(1904.4)	239.5	(1630.7)
BYS, T, ksi (MPa)	303.8	(2094.7)	275.1	(1896.8)	231.6	(1596.9)
Fracture Toughness[b]						
K_c, L, ksi$\sqrt{\text{in.}}$ (MPa $\cdot$ $m^{\frac{1}{2}}$)	177.8	(195.6)	NA[c]		NA	
K_c, T, ksi$\sqrt{\text{in.}}$ (MPa $\cdot$ $m^{\frac{1}{2}}$)	231.0	(254.1)	NA		NA	

(Continued)

Properties	RT	(RT)	400	(477)	800	(700)
	Temperature, F (K)					
Axial Fatigue (Transverse)						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	198	(1365)	172	(1186)	150	(1034)
10^5 cycles, ksi (MPa)	109	(751)	111	(765)	128	(882)
10^7 cycles, ksi (MPa)	95	(655)	95	(655)	115	(793)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	140	(965)	140	(965)	132	(910)
10^5 cycles, ksi (MPa)	38	(262)	42	(290)	37	(255)
10^7 cycles, ksi (MPa)	35	(241)	40	(276)	35	(241)
Creep (Transverse)						
0.2% plastic deformation, 100 hr, ksi (MPa)	NA		NA		98	(676)
0.2% plastic deformation, 1000 hr, ksi (MPa)	NA		NA		74	(510)
Stress Rupture (Transverse)						
Rupture, 100 hr, ksi (MPa)	NA		NA		134	(924)
Rupture, 1000 hr, ksi (MPa)	NA		NA		122	(841)
Bend						
Minimum Radius, in. (mm)	.125	(3.18)	NA		NA	

Coefficient of Thermal Expansion

6.37 in./in. F x 10^{-6} (From RT to 800 F)
11.47 cm/cm C x 10^{-6} (From RT to 427 C)

Density

0.28 lb./in.^{3} (7.75 g/cm^3)

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) Average of three tests in each direction.

(c) NA, not applicable.

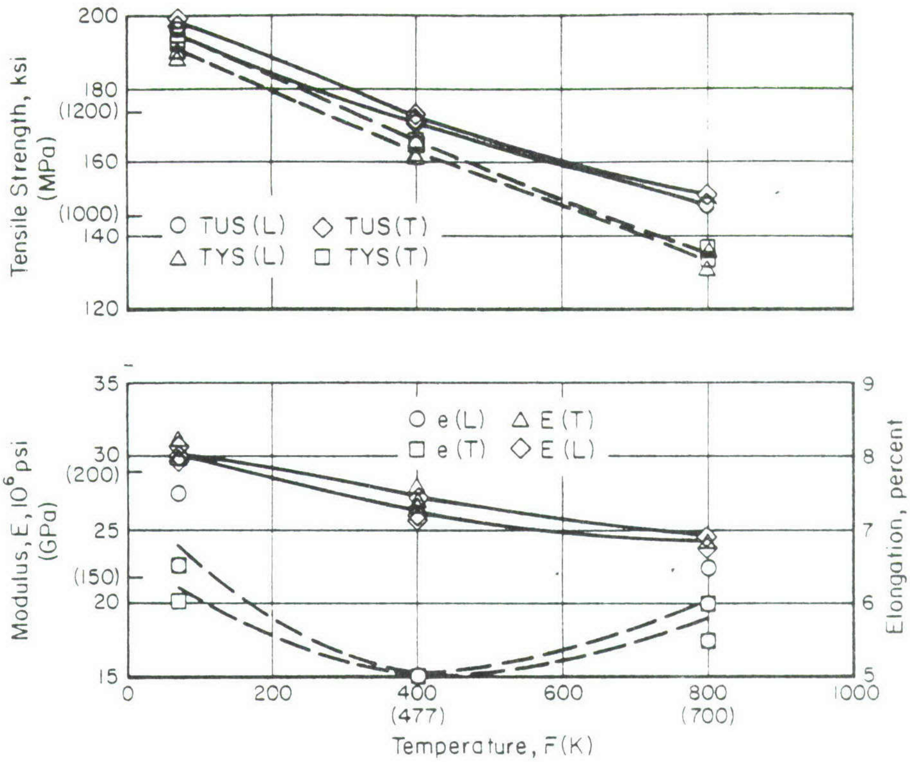


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CUSTOM 450 STAINLESS STEEL

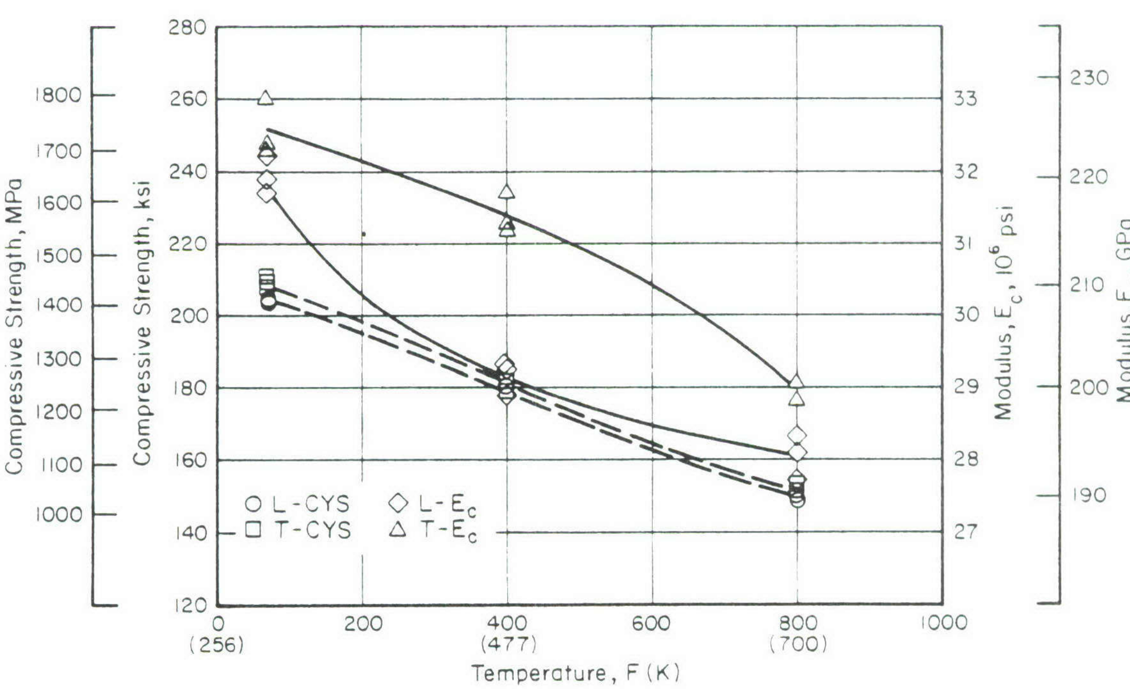


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF CUSTOM 450 STAINLESS STEEL

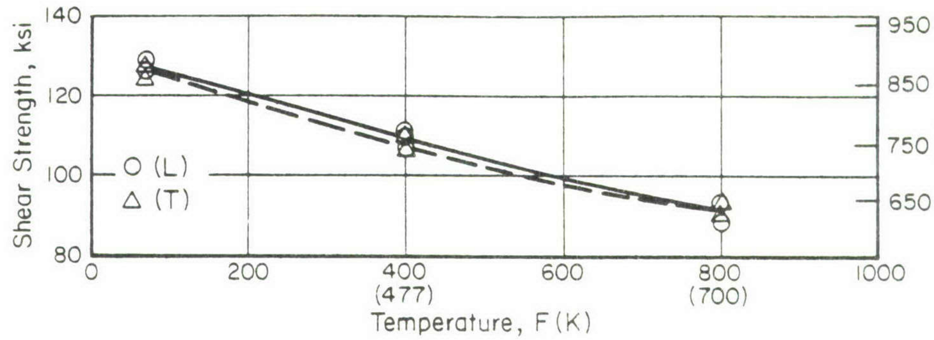


FIGURE 3. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF CUSTOM 450 STAINLESS STEEL

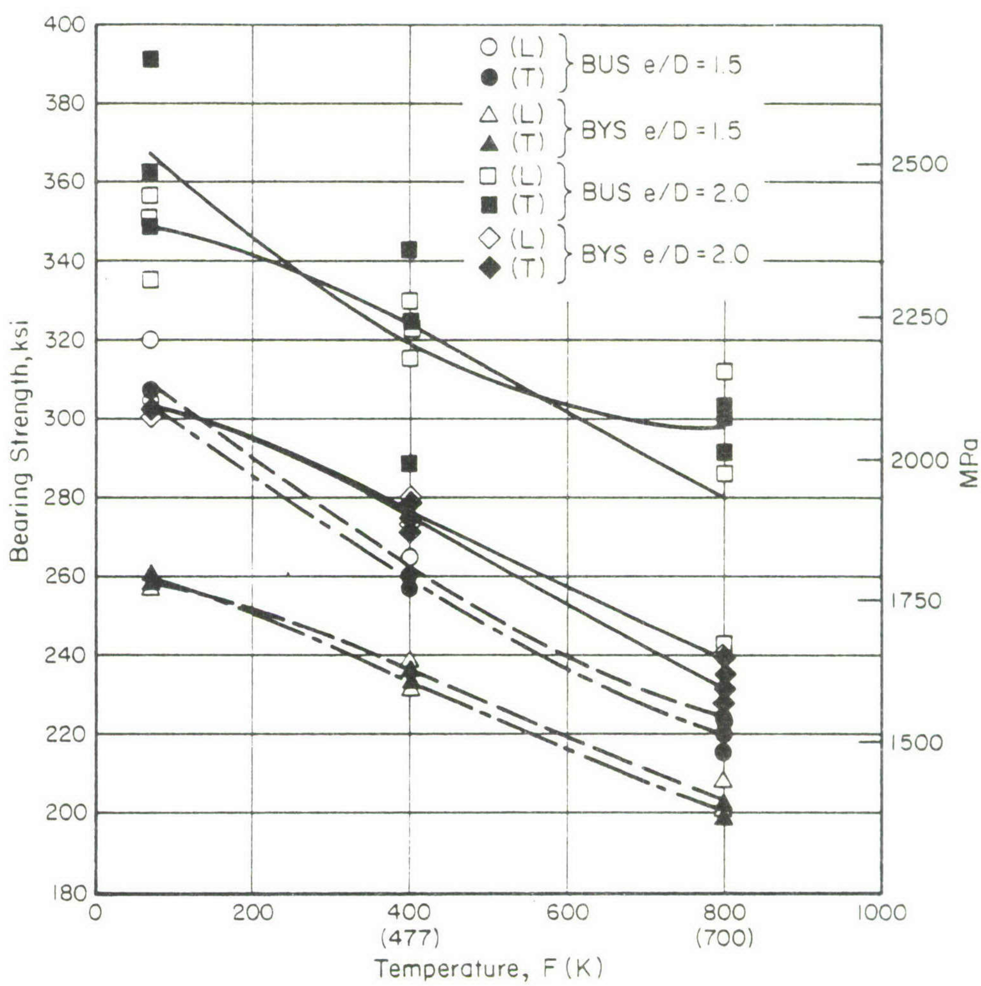


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF CUSTOM 450 STAINLESS STEEL

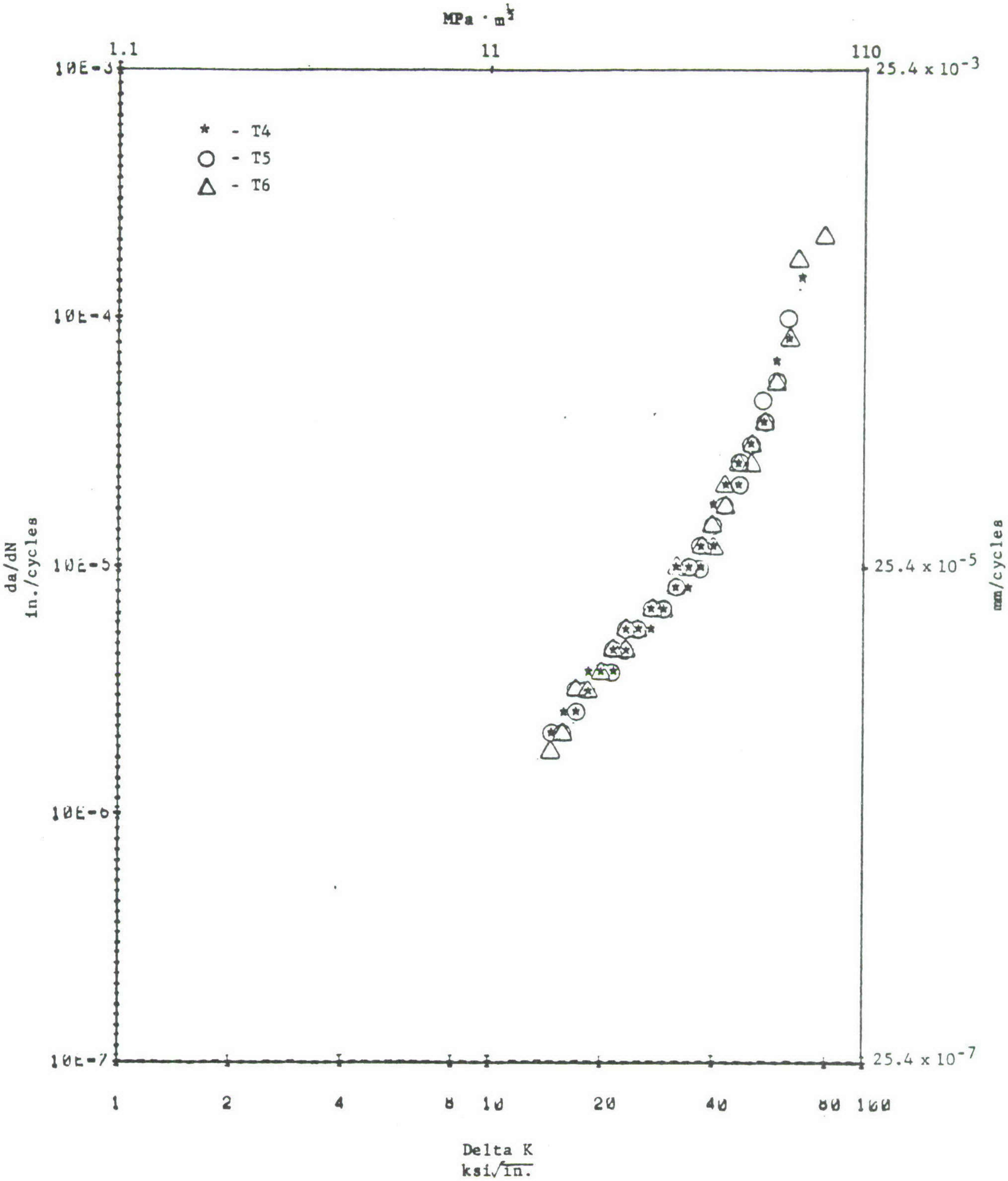


FIGURE 5. da/dN VERSUS DELTA K FOR CUSTOM 450 STAINLESS STEEL

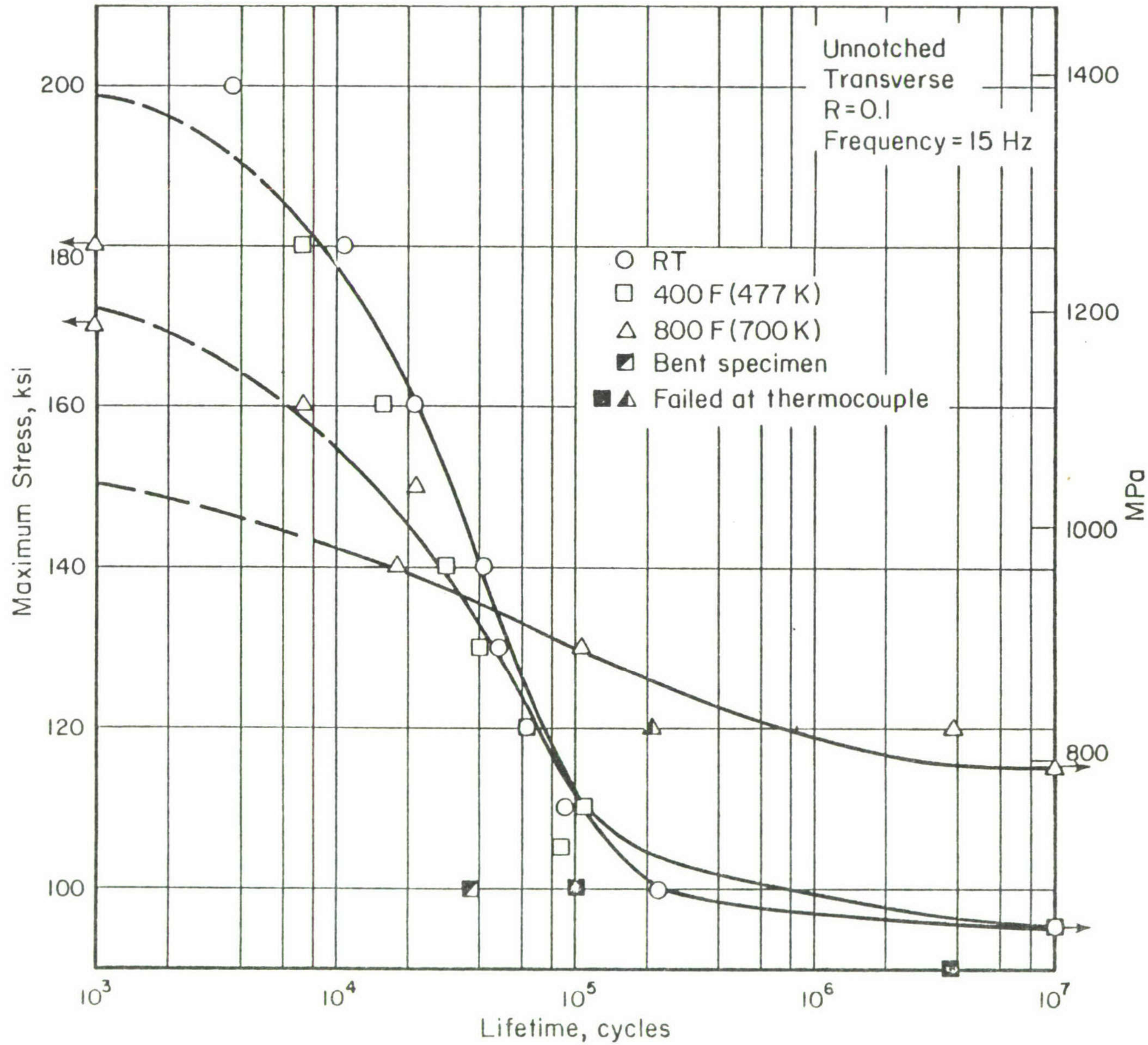


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED CUSTOM 450 STAINLESS STEEL STRIP

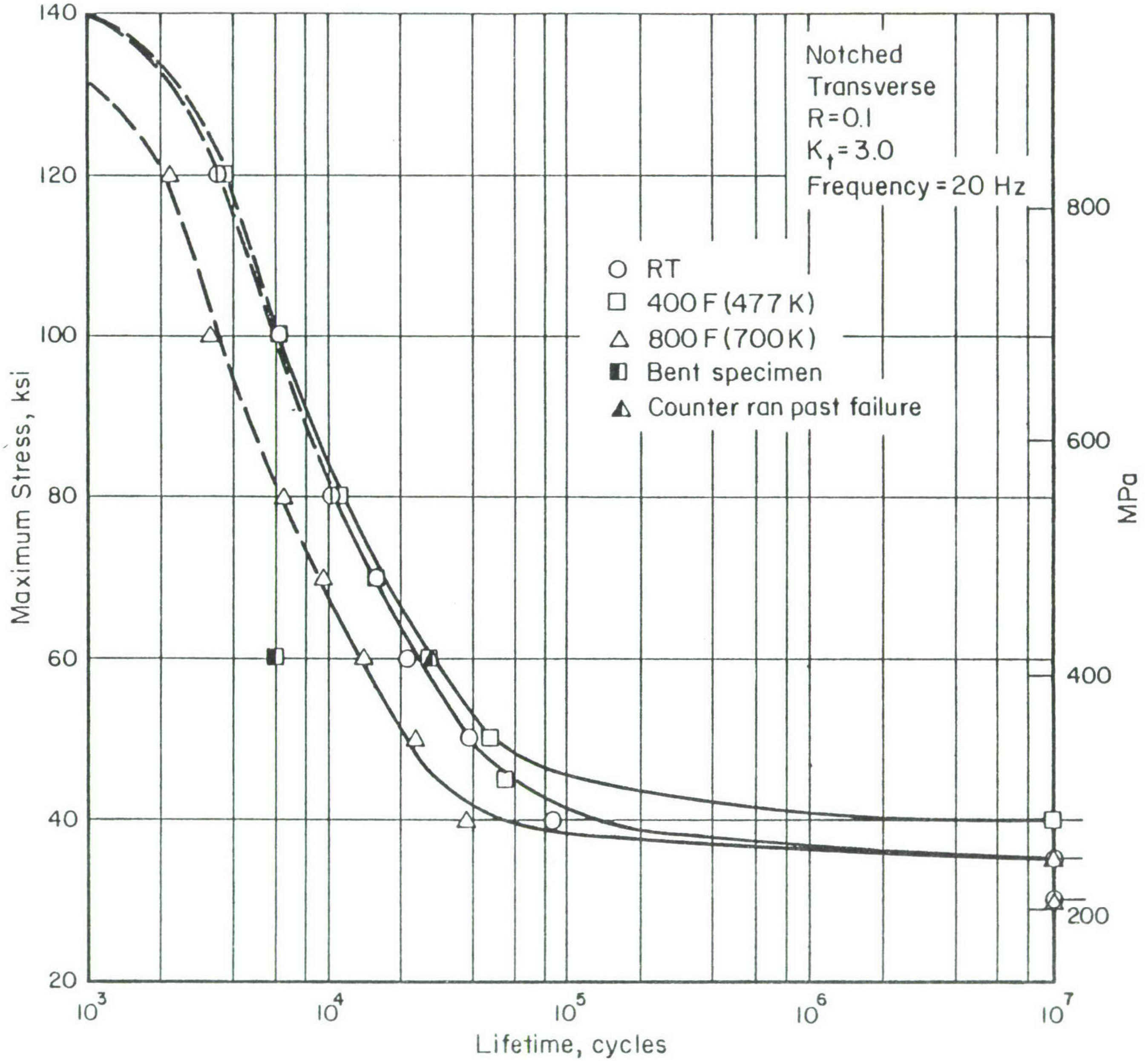


FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) CUSTOM 450 STAINLESS STEEL STRIP

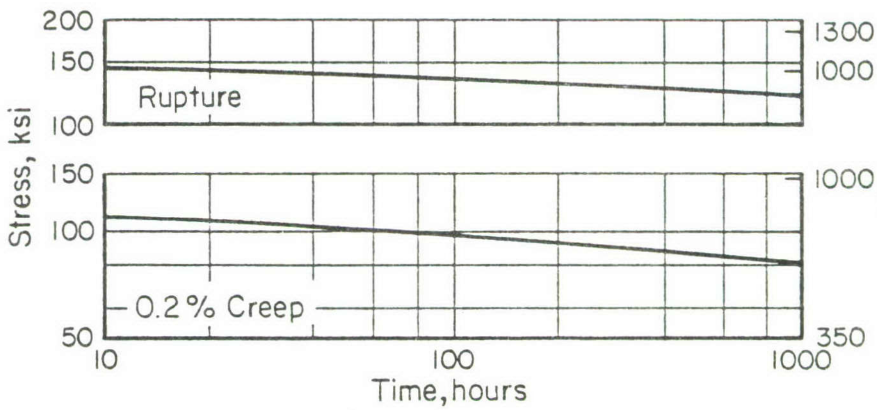


FIGURE 8. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR CUSTOM 450 STAINLESS STEEL

Ti-15V-3Cr-3Al-3Sn Alloy

Material Description

This alloy is a recent development of Timet. The development aim was for a formable, heat-treatable, high-toughness sheet material as a possible higher-strength replacement for Ti-6Al-4V in various applications.

The Ti-15V-3Cr-3Al-3Sn sheet used in this evaluation was nominally 0.080-inch (2.032 mm) thick, from Timet heat number P2360. The alloy was supplied in the solution-annealed condition. The composition was as follows:

Chemical Composition	Percent
C	.015
Fe	.16
N	.014
Al	3.2
Cr	3.2
V	15.0
Sn	3.1
H	.017
O	.11

Processing and Heat Treating

Specimens were heat treated at 925 F (769 K) for 8 hours and air cooled. This heat treatment was selected, after discussions with Timet personnel, to achieve optimum fracture toughness for the alloy. Other treatments may be used to obtain different strength properties.

Ti-15V-3Cr-3Al-3Sn ALLOY[a]

Condition: Solution treated and aged 925 F - 8 hours
Thickness: 0.080 inch (2.032 mm) sheet

Properties	Temperature, F (K)					
	RT	(RT)	400	(477)	800	(700)
Tension						
TUS, L, ksi (MPa)	178.3	(1229.4)	164.3	(1132.8)	144.9	(999.1)
TUS, T, ksi (MPa)	180.6	(1245.2)	166.3	(1146.6)	146.5	(1010.1)
TYS, L, ksi (MPa)	163.4	(1126.6)	142.2	(980.5)	121.4	(837.1)
TYS, T, ksi (MPa)	166.4	(1147.3)	144.5	(996.3)	123.8	(853.6)
e, L, percent in 2 in. (50.8 mm)	8.7	(8.7)	7.8	(7.8)	13.0	(13.0)
e, T, percent in 2 in. (50.8 mm)	8.2	(8.2)	7.3	(7.3)	11.3	(11.3)
E, L, 10^3 ksi (GPa)	14.4	(99.3)	13.4	(92.4)	12.3	(84.8)
E, T, 10^3 ksi (GPa)	14.3	(98.6)	13.6	(93.8)	12.1	(83.4)
Compression						
CYS, L, ksi (MPa)	172.1	(1186.6)	157.5	(1053.6)	142.6	(983.2)
CYS, T, ksi (MPa)	178.6	(1231.2)	159.2	(1097.5)	138.7	(956.6)
E_c, L, 10^3 ksi (GPa)	15.7	(108.3)	15.3	(105.5)	13.4	(92.2)
E_c, T, 10^3 ksi (GPa)	16.0	(110.3)	15.3	(105.5)	13.3	(91.9)
Shear						
SUS, L, ksi (MPa)	113.7	(784.2)	103.1	(710.6)	92.3	(636.2)
SUS, T, ksi (MPa)	115.9	(798.9)	102.3	(705.1)	92.4	(636.9)
Bearing						
e/D = 1.5						
BUS, L, ksi (MPa)	288.2	(1987.1)	247.3	(1705.1)	241.7	(1666.5)
BUS, T, ksi (MPa)	272.3	(1877.5)	253.2	(1745.8)	239.5	(1651.4)
BYS, L, ksi (MPa)	244.9	(1688.6)	224.1	(1545.2)	211.8	(1460.4)
BYS, T, ksi (MPa)	252.8	(1743.1)	225.9	(1557.6)	207.5	(1430.7)
e/D = 2.0						
BUS, L, ksi (MPa)	323.6	(2231.2)	298.4	(2057.3)	290.9	(2005.8)
BUS, T, ksi (MPa)	336.9	(2322.9)	299.1	(2062.3)	297.1	(2048.5)
BYS, L, ksi (MPa)	265.4	(1829.9)	255.6	(1762.4)	234.2	(1614.8)
BYS, T, ksi (MPa)	288.5	(1989.2)	260.3	(1794.8)	238.5	(1644.5)
Fracture Toughness						
K_c, L, $ksi\sqrt{in.}$ $(MPa \cdot m^{\frac{1}{2}})$	90.4	(99.4)	NA[b]		NA	
K_c, T, $ksi\sqrt{in.}$ $(MPa \cdot m^{\frac{1}{2}})$	90.9	(100.0)	NA		NA	

Ti-15V-3Cr-3Al-3Sn (Continued)

Properties	RT	(RT)	800	(700)
	Temperature			
Axial Fatigue (Transverse)				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	180.0	(1241.1)	146.0	(1006.7)
10^5 cycles, ksi (MPa)	66.0	(455.1)	70.0	(482.6)
10^7 cycles, ksi (MPa)	55.0	(379.2)	65.0	(448.2)
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	92.0	(634.3)	92.0	(634.3)
10^5 cycles, ksi (MPa)	23.5	(162.0)	29.0	(200.0)
10^7 cycles, ksi (MPa)	17.5	(120.7)	27.0	(186.2)
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi (MPa)	NA		21	(144.8)
0.2% plastic deformation, 1000 hr, ksi (MPa)	NA		15	(103.4)
Stress Rupture (Transverse)				
Rupture, 100 hr, ksi (MPa)	NA		105	(724.0)
Rupture, 1000 hr, ksi (MPa)	NA		70	(482.6)
Bend				
Minimum Radius, in. (mm)	.625	(15.88)	NA	NA
Coefficient of Thermal Expansion				
5.5 in./in. F x 10^{-6} (RT to 800 F)				
9.9 m/(m·K) x 10^{-6} (RT to 700 K)				
Density				
0.172 lb./in.^{3} (4.76 g/cm^3)				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using the results of a greater number of tests.

(b) NA, not applicable.

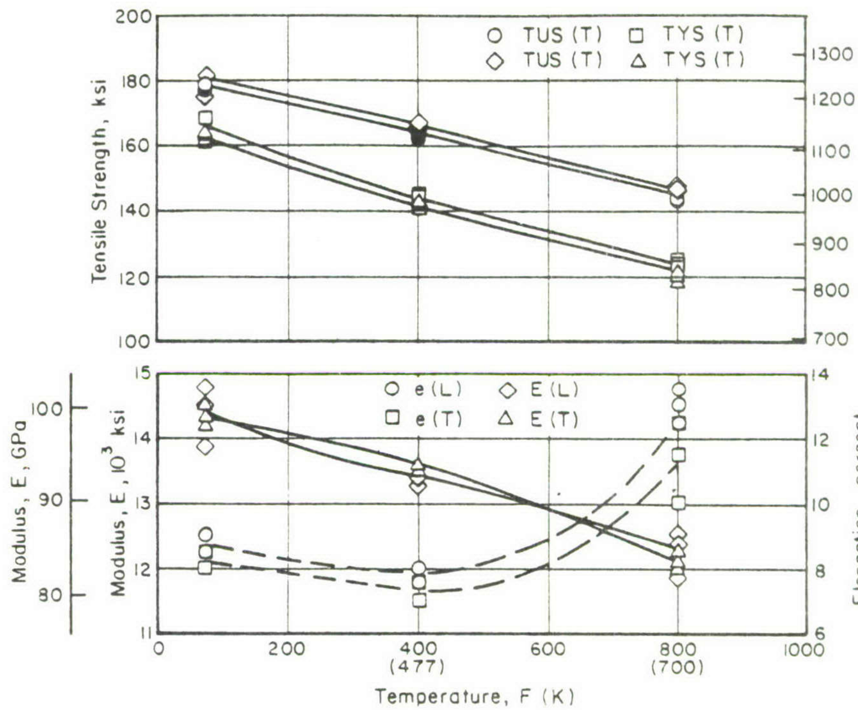


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

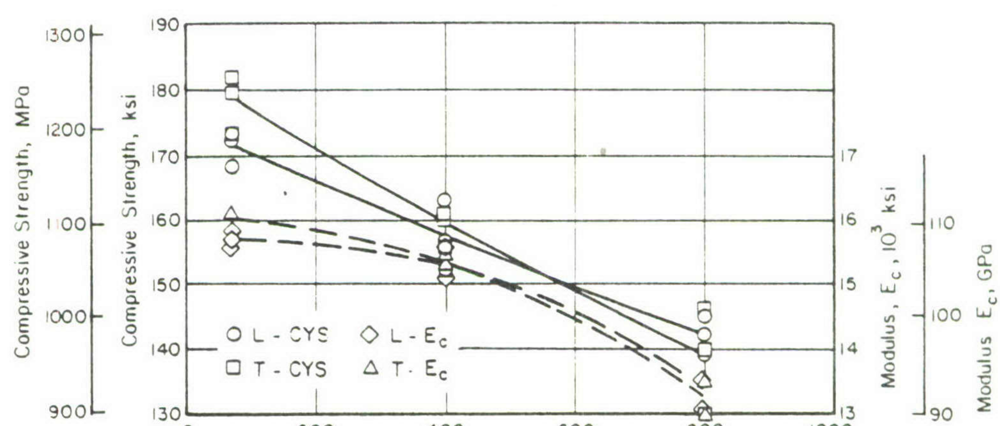


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

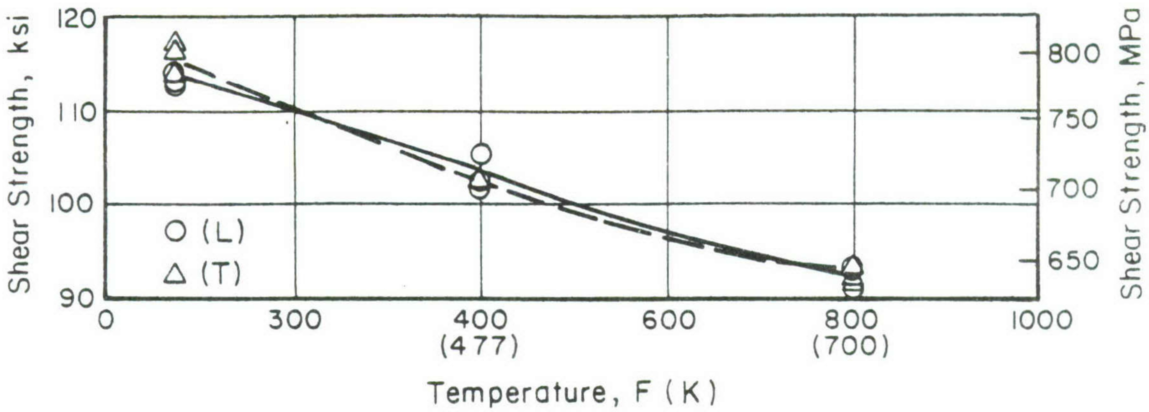


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

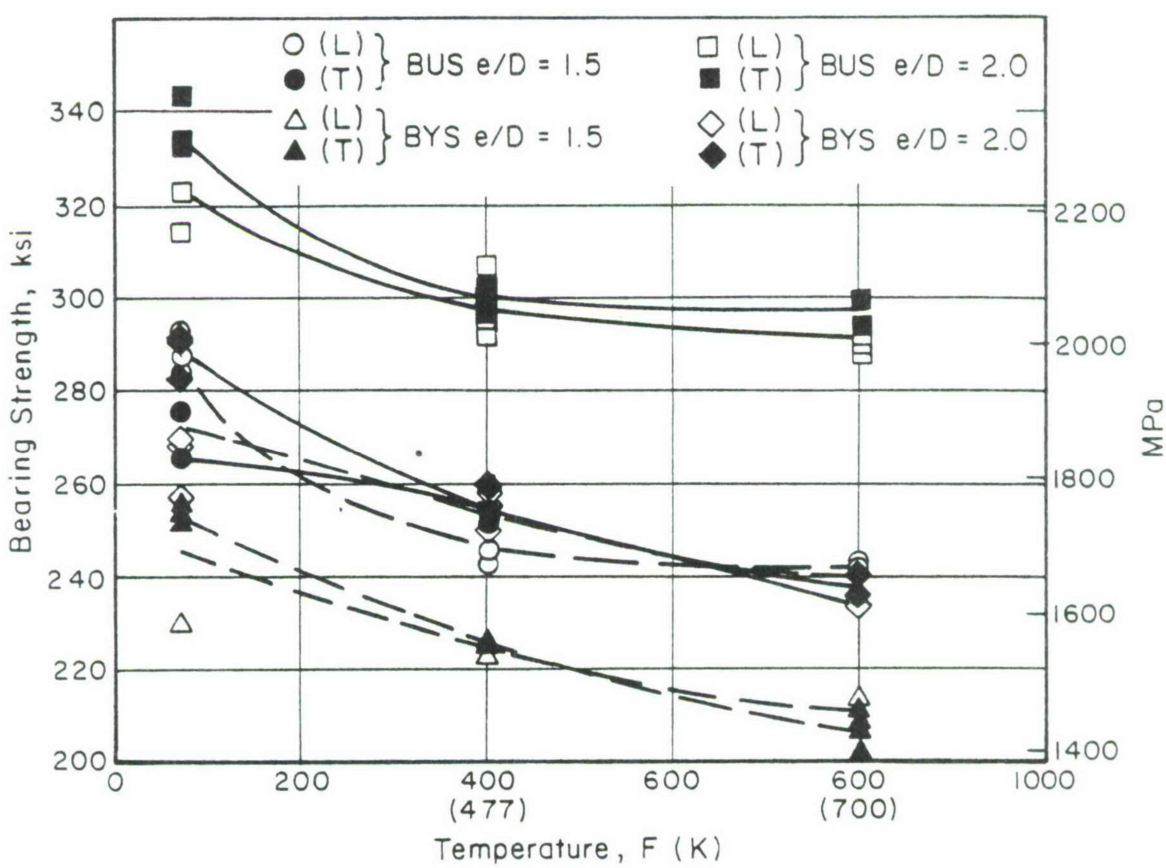


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

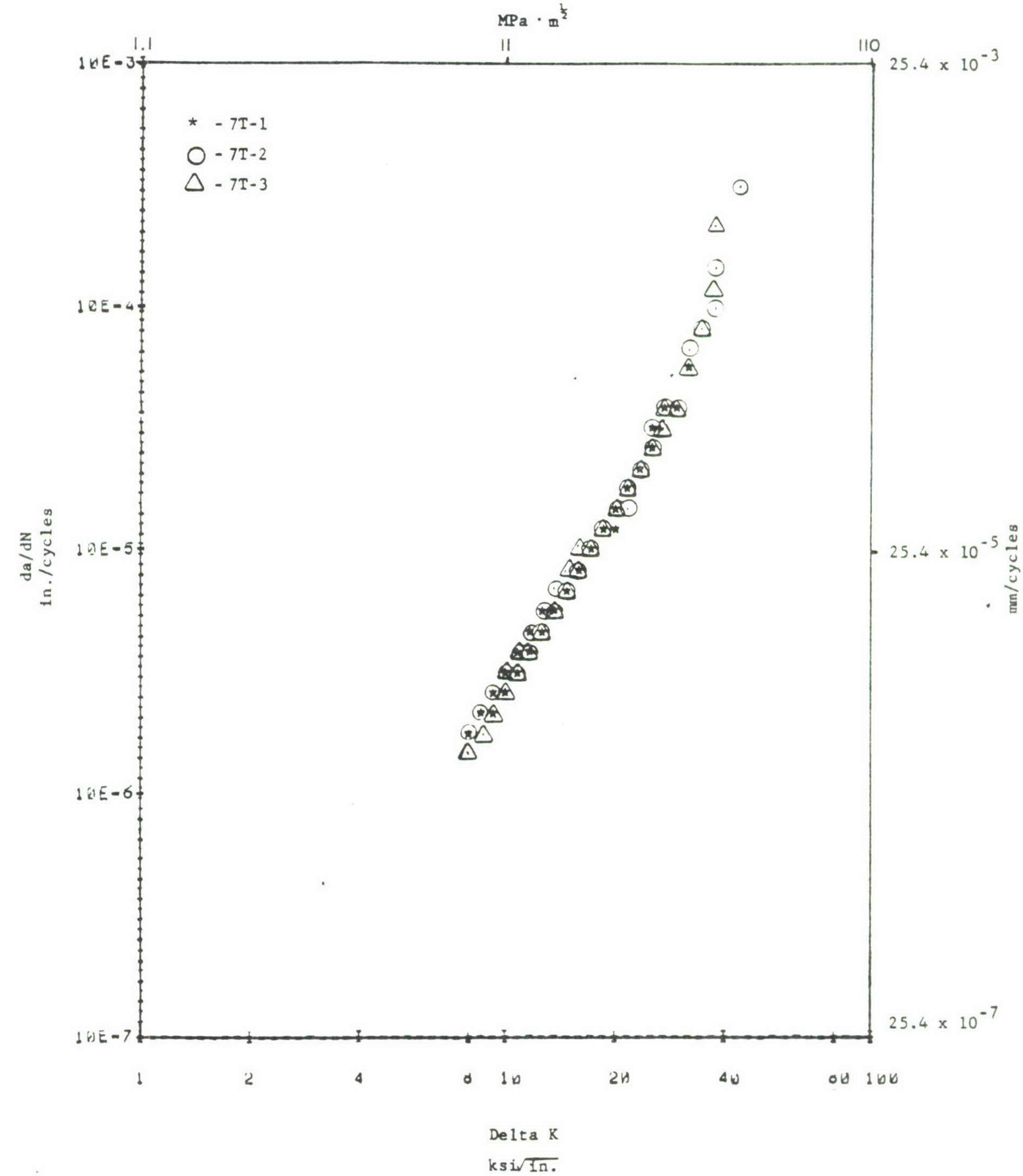


FIGURE 5. da/dN VERSUS DELTA K FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

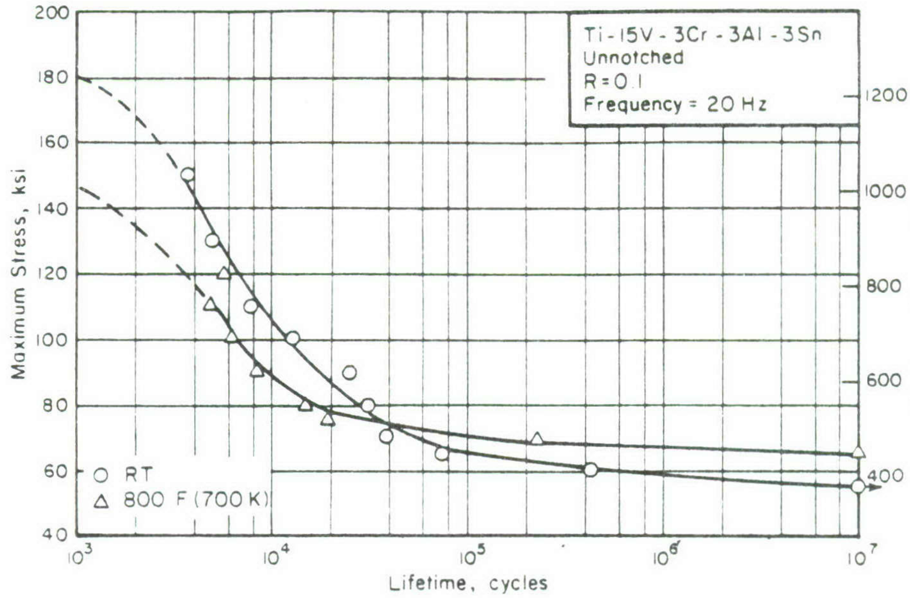


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

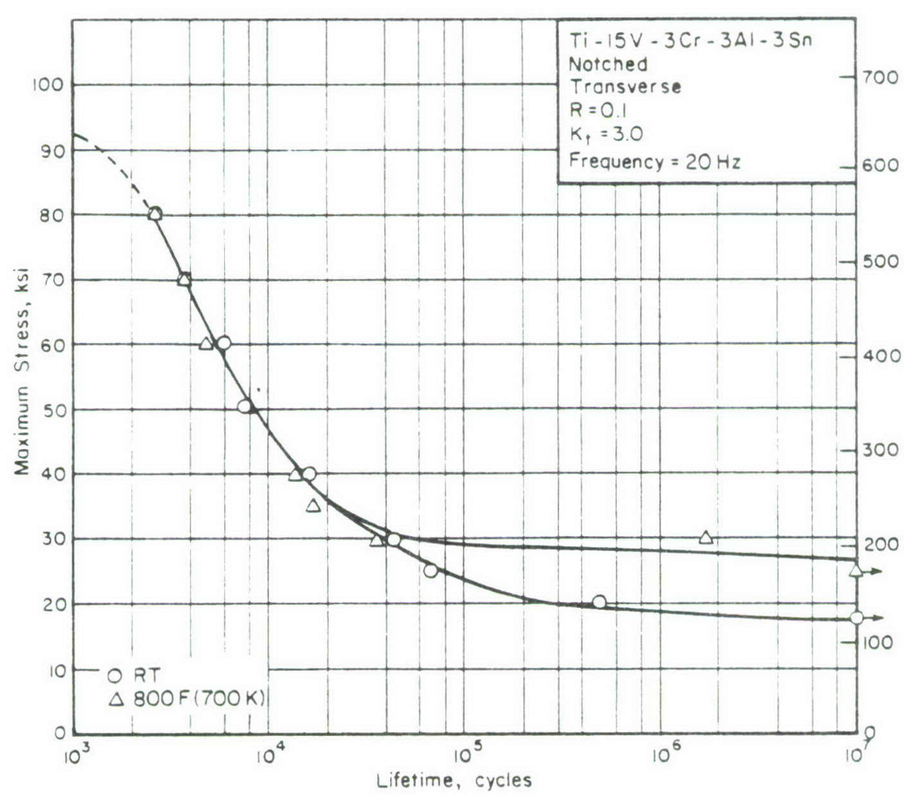


FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

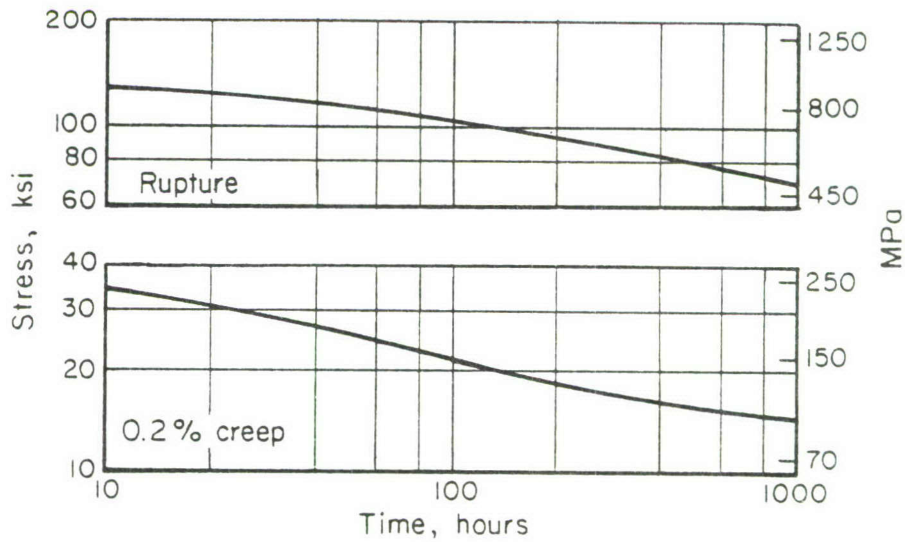


FIGURE 8. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

A206-T7 Aluminum Castings

Material Description

A206 is a high-strength, aluminum casting alloy. The purpose of the alloy development was to preserve as much of the ductility and mechanical property gain of the previous development in Alloy 201 while reducing alloy costs to a level comparable to other premium casting alloys (e.g., A356-A357, etc.).

The material used in this evaluation was permanent mold, cast rectangular shapes of various thicknesses and sizes. The material was obtained through Trialco, Inc., and had the following composition:

Chemical Composition	Percent
Si	.02
Fe	.07
Cu	4.9
Mn	.24
Mg	.22
Ti	.14

Processing and Heat Treating

The alloy was evaluated in the as-received -T7 condition.

A206-T7 ALUMINUM CASTING[a]

Condition: -T7
Thickness: Various

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
Tension						
TUS, ksi (MPa)	63.2	(435.8)	55.7	(384.1)	48.3	(333.0)
TYS, ksi (MPa)	50.3	(346.8)	45.9	(316.5)	43.8	(302.0)
e, percent in 2 in. (50.8 mm)	11.7	(11.7)	14.0	(14.0)	17.7	(17.7)
RA, percent	26.0	(26.0)	40.4	(40.4)	53.7	(53.7)
E, 10^3 ksi (GPa)	10.2	(70.3)	10.0	(69.0)	9.4	(64.8)
Compression						
CYS, ksi (MPa)	53.9	(371.6)	50.3	(346.8)	46.2	(318.5)
E_c, 10^3 ksi (GPa)	10.2	(70.3)	9.6	(66.2)	8.9	(61.4)
Shear						
SUS, ksi (MPa)	37.30	(257.2)	33.69	(232.3)	30.14	(207.8)
Bearing						
e/D = 1.5						
BUS, ksi (MPa)	100.4	(692.5)	91.9	(632.5)	79.1	(545.2)
BYS, ksi (MPa)	78.9	(544.2)	73.5	(506.6)	69.2	(477.1)
e/D = 2.0						
BUS, ksi (MPa)	131.4	(906.0)	113.6	(783.5)	92.1	(634.7)
BYS, ksi (MPa)	95.5	(658.2)	91.1	(627.9)	82.1	(566.1)
Fracture Toughness						
K_{Ic}, ksi$\sqrt{in.}$ (MPa$\cdot$m$^{\frac{1}{2}}$)[b]	39.2	(43.1)	U[c]	U	U	

Properties	Temperature, F (K)			
	RT	(RT)	350	(450)
<u>Axial Fatigue</u>				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	63	(434)	51	(352)
10^5 cycles, ksi (MPa)	42	(290)	36	(248)
10^7 cycles, ksi (MPa)	30	(207)	23	(159)
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	54	(372)	54	(372)
10^5 cycles, ksi (MPa)	17	(117)	17	(117)
10^7 cycles, ksi (MPa)	10	(89)	10	(69)

<u>Coefficient of Thermal Expansion</u>

10.7 in./in./F x 10^{-6} (RT to 212 F)
19.3 m/(m·K) x 10^{-6} (RT to 373 K)

<u>Density</u>

0.101 lb./in.^{3} (2.80 g/cm^3)

(a) Values are average of triplicate test conducted at Battelle under the subject contract unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) Invalid K_{Ic} per ASTM E399.

(c) U - Unavailable.

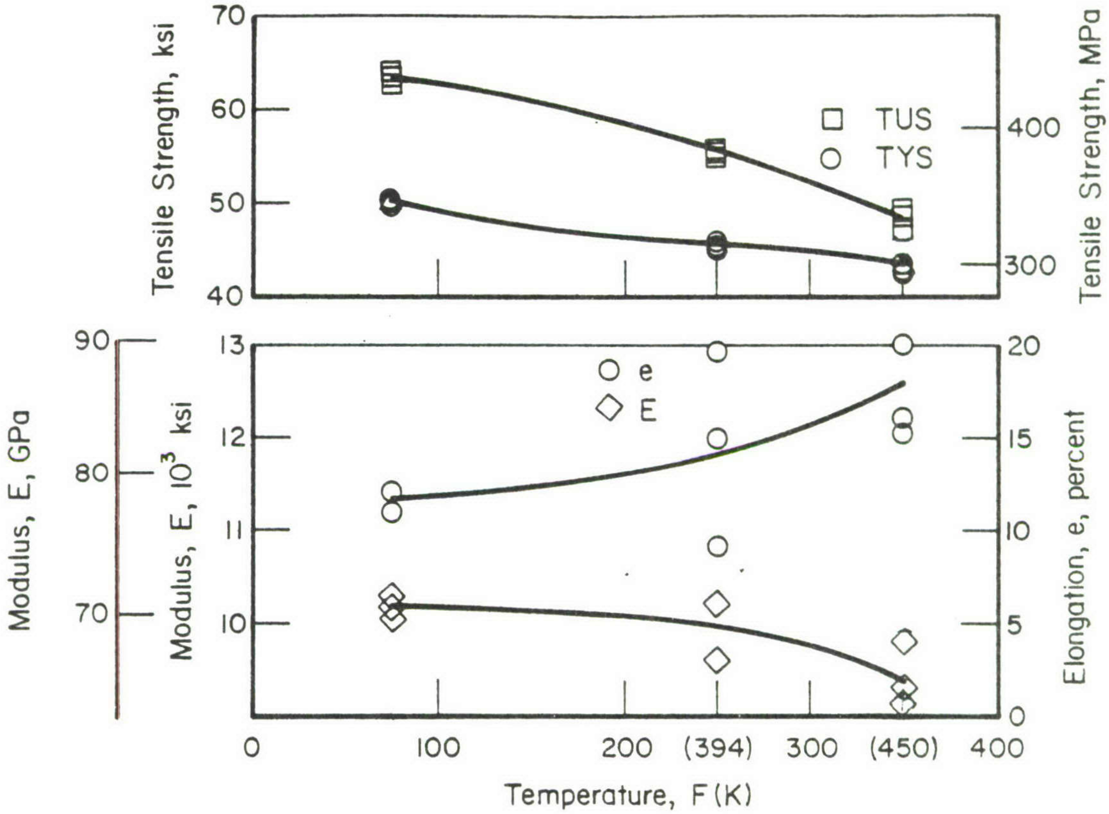


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF A 206-T7 ALUMINUM CASTING

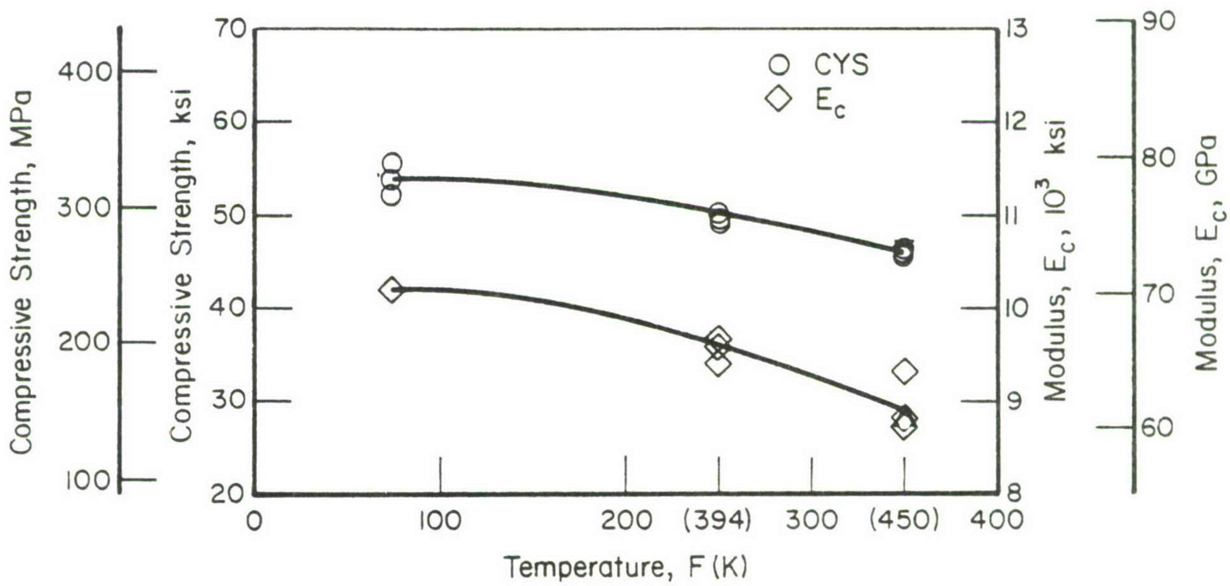


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF A 206-T7 ALUMINUM CASTING

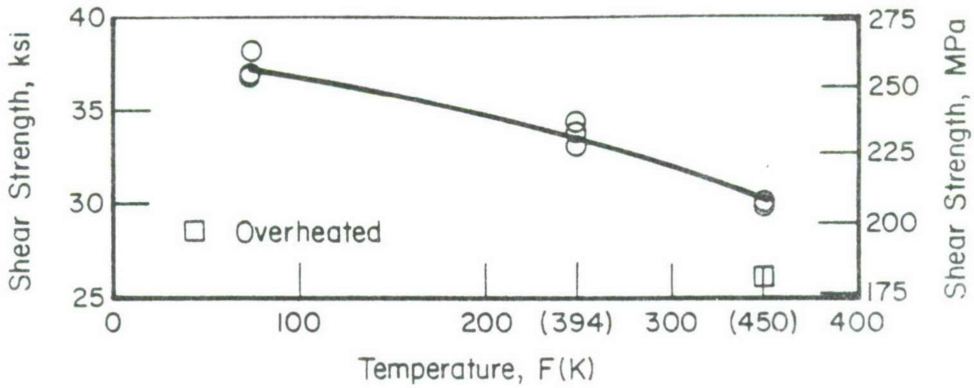


FIGURE 3. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF A 206-T7 ALUMINUM CASTING

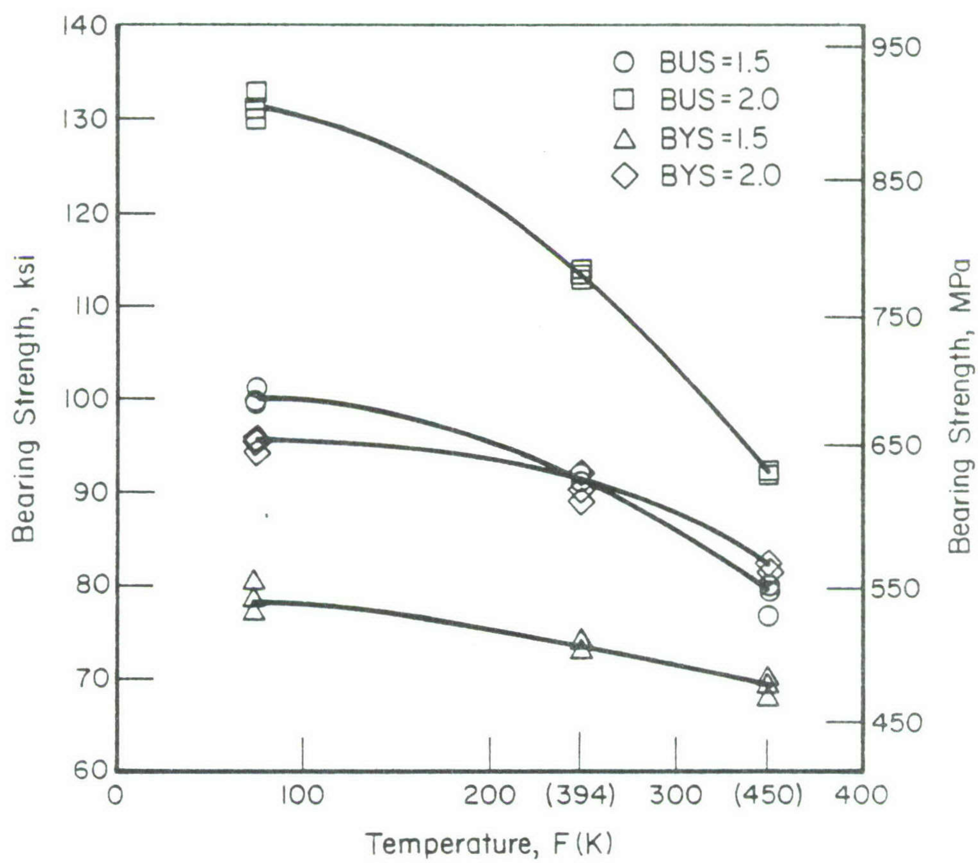


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF A 206-T7 ALUMINUM CASTING

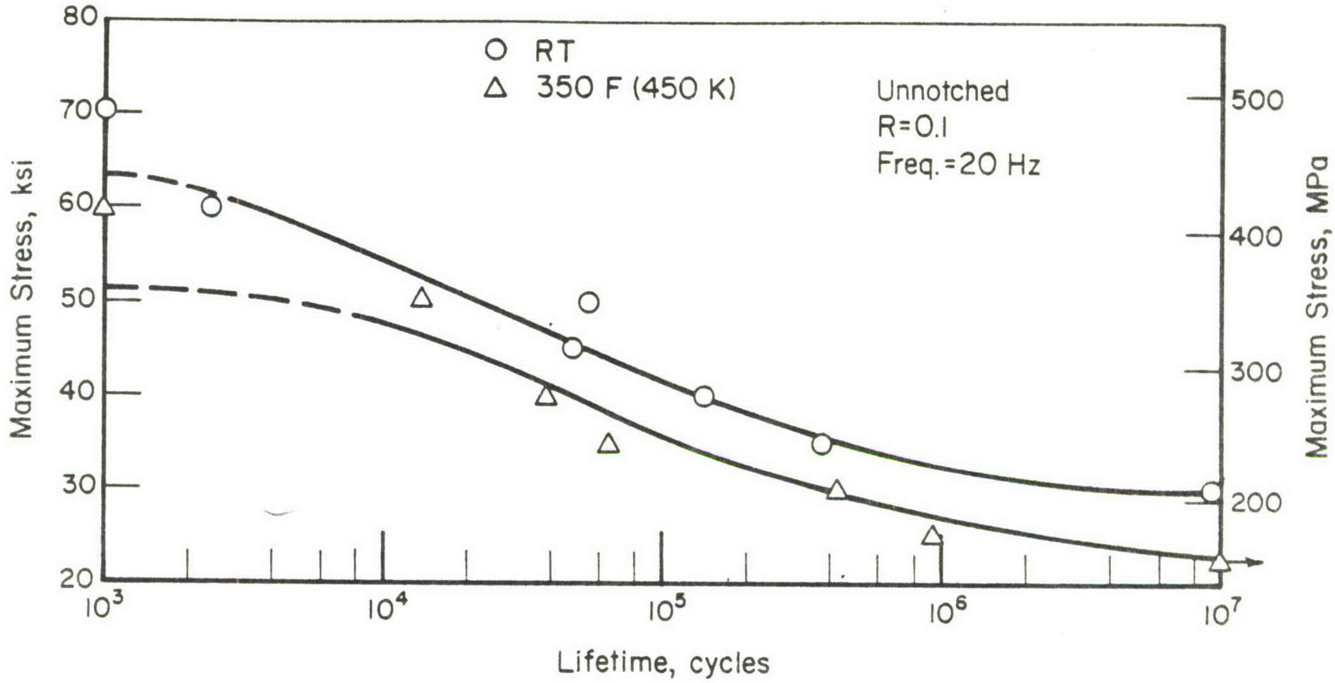


FIGURE 5. AXIAL LOAD BEHAVIOR OF UNNOTCHED A 206-T7 ALUMINUM CASTING

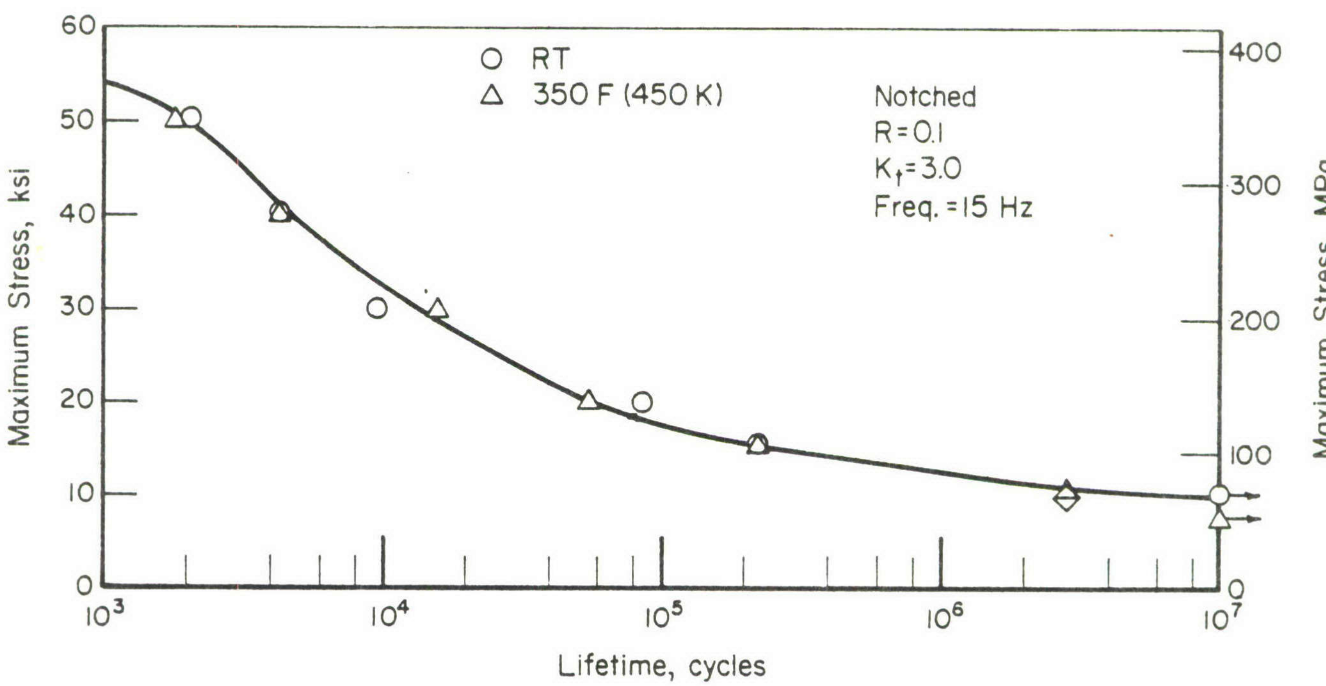


FIGURE 6. AXIAL LOAD BEHAVIOR OF NOTCHED A 206-T7 ALUMINUM CASTING

224-T6 Aluminum Castings

Material Description

Alloy 224 is a heat-treatable premium aluminum casting alloy. When solution heat treated and overaged, it possesses good mechanical properties at elevated temperatures. It also has good fatigue properties and toughness.

The material used in this evaluation was obtained through Eck Industries, Inc. as a swivel bracket casting. The composition is within the following:

Chemical Composition	Percent min. - max.
Cu	4.5 - 5.5
Mn	0.20 - 0.50
Zr	0.10 - 0.25
V	0.05 - 0.15
Ti	-- 0.35
Fe	-- 0.10
Si	-- 0.06
other impurities, total	0.10
Al	remainder

Processing and Heat Treating

The alloy was evaluated in the as-received -T6 condition.

224 ALUMINUM CASTING[a,c]

Condition: T6
Thickness: Various

Properties	Temperature, F (K)					
	RT	RT	250	(394)	350	(450)
Tension						
TUS, ksi (MPa)	53.0	(365.7)	41.9	(289.1)	36.8	(254.0)
TYS, ksi (MPa)	30.0	(206.9)	26.9	(185.5)	26.8	(184.8)
e , percent in 2 in. (50.8 mm)	13.3	(13.3)	16.0	(16.0)	14.3	(14.3)
RA , percent	15.5	(15.8)	30.3	(30.3)	25.7	(25.7)
E , 10^3 ksi (GPa)	9.9	(68.3)	9.4	(64.8)	9.4	(64.8)
Compression						
CYS, ksi (MPa)	33.3	(229.6)	31.8	(219.0)	29.4	(202.7)
E_c , 10^3 ksi (GPa)	10.5	(72.4)	8.6	(59.3)	8.6	(59.5)
Shear						
SUS, ksi (MPa)	35.2	(242.7)	29.4	(202.5)	24.1	(166.2)
Bearing						
e/D = 1.5						
BUS, ksi (MPa)	91.6	(631.6)	U[b]		U	
BYS, ksi (MPa)	61.9	(426.5)	U		U	
e/D = 2.0						
BUS, ksi (MPa)	106.3	(732.9)	U		U	
BYS, ksi (MPa)	71.4	(492.3)	U		U	

Properties	Temperature, F (K) RT (RT)
Axial Fatigue	
Unnotched, R = 0.1	
10^3 cycles, ksi (MPa)	53 (366)
10^5 cycles, ksi (MPa)	29 (200)
10^7 cycles, ksi (MPa)	16 (110)
Notched, K_t = 3.0, R = 0.1	
10^3 cycles, ksi (MPa)	46 (317)
10^5 cycles, ksi (MPa)	24 (165)
10^7 cycles, ksi (MPa)	15 (103)
Coefficient of Thermal Expansion	
10.7 in./in./F x 10^{-6} (RT to 212 F)	
19.3 m/(m·K) x 10^{-6} (RT to 373 K)	
Density	
0.102 lb./in.^{3} (2.823 g/cm^3)	

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) U, unavailable.

(c) Casting section size was not sufficient to obtain fracture toughness specimens.

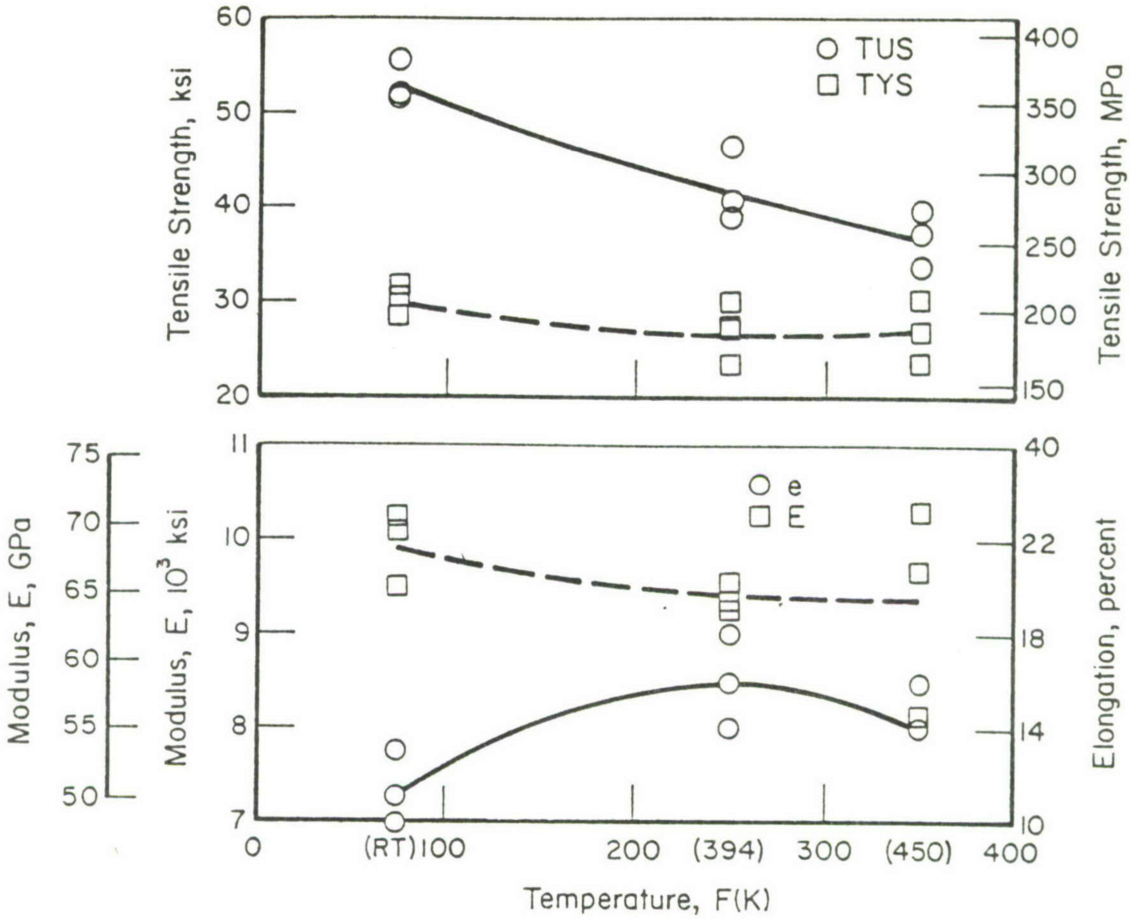


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 224-T6 ALUMINUM CASTINGS

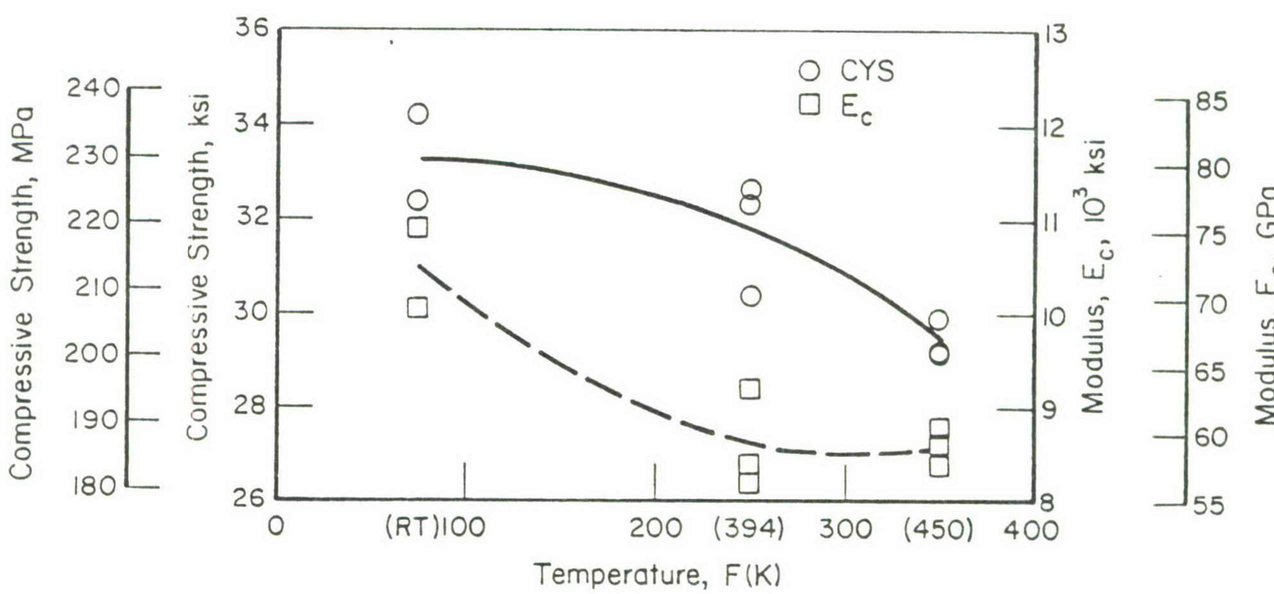


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 224-T6 ALUMINUM CASTINGS

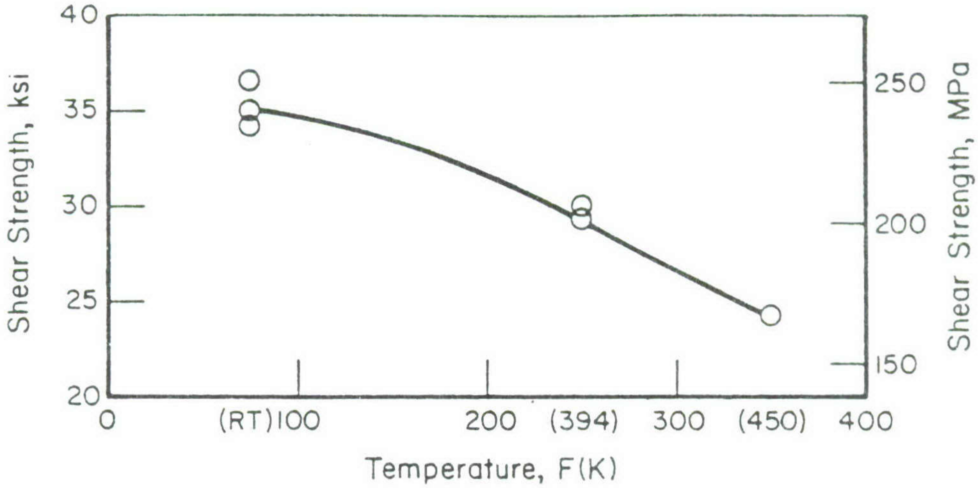


FIGURE 3. EFFECT OF TEMPERATURE ON PIN SHEAR PROPERTIES OF 224-T6 ALUMINUM CASTINGS

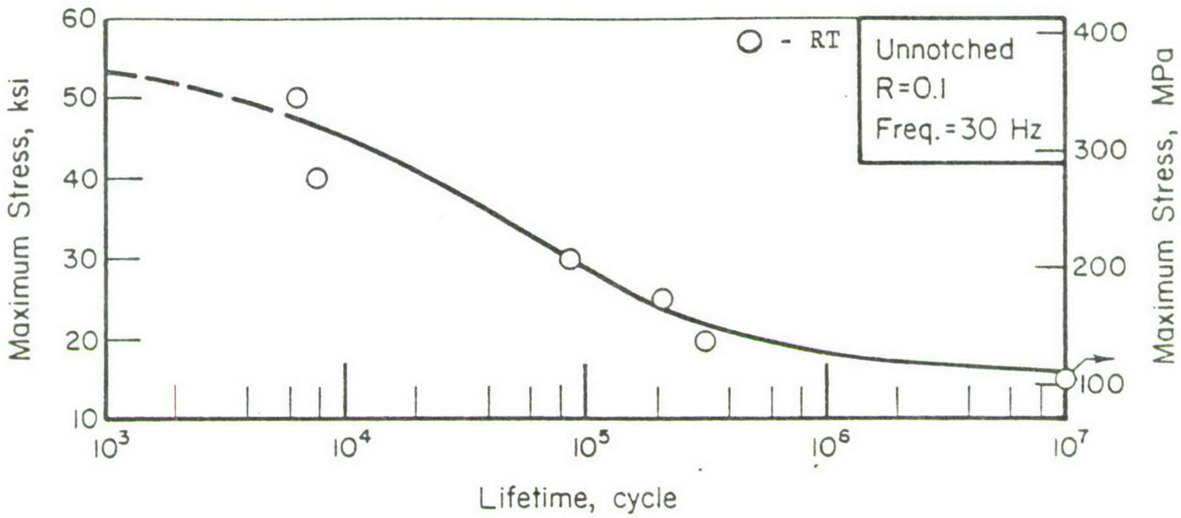


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 224-T6 ALUMINUM CASTINGS

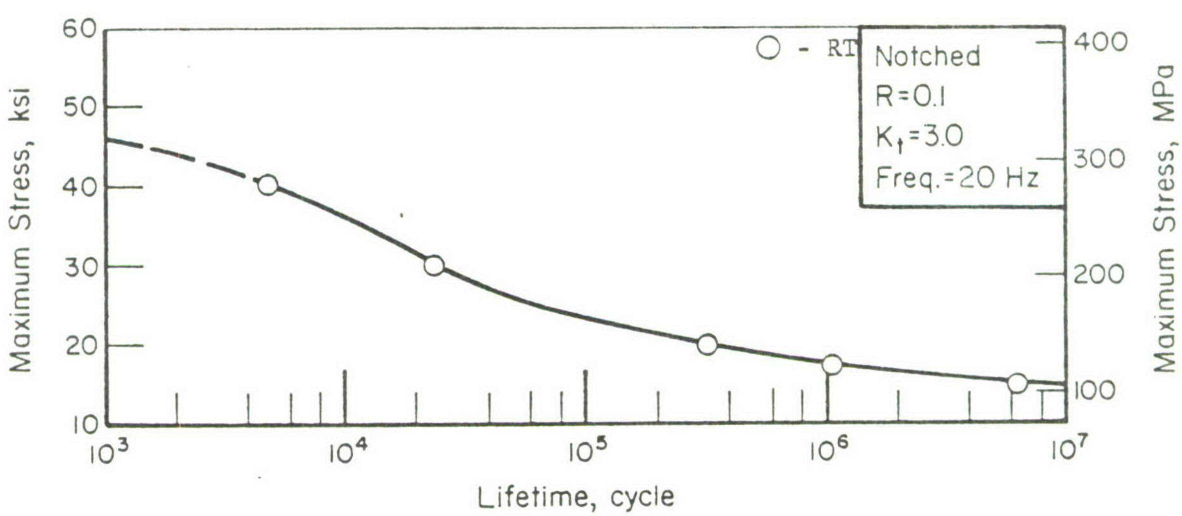


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 224-T6 ALUMINUM CASTINGS

C355-T61 Cast Aluminum Alloy

Material Description

C355 alloy is similar to 355 aluminum alloy but C355 has the impurities controlled to lower limits, thus resulting in higher strengths.

The material used in this evaluation was obtained through Morris Bean and Company as impellers castings. The composition is within the following:

Chemical Composition	Percent, minimum - maximum
Cu	1.0 - 1.5
Si	4.5 - 5.5
Fe	0.20
Mg	0.4 - 0.6
Ti	0.20
Others	0.15
Al	Remainder

Processing and Heat Treating

The alloy was evaluated in the as-received -T61 condition.

C355-T61 ALUMINUM CASTING[a]

Condition: -T61

Thickness: Various

Properties	Temperature, F (K) RT	(RT)	250	(394)	350	(450)
Tension						
TUS, ksi (MPa)	51.5	(355.1)	45.0	(310.3)	40.0	(275.8)
TYS, ksi (MPa)	37.7	(259.9)	35.4	(244.1)	33.9	(233.7)
e, percent in 2 in. (50.8 mm)	9	(9)	15	(15)	11	(11)
E, 10^3 ksi (GPa)	10.8	(74.5)	10.2	(70.3)	8.6	(59.3)
Compression						
CYS, ksi (MPa)	39.4	(271.7)	38.0	(261.8)	35.0	(241.6)
E_c, 10^3 ksi (GPa)	9.3	(64.1)	9.0	(62.0)	9.0	(62.1)
Shear						
SUS, ksi (MPa)	33.0	(227.5)	27.1	(200.6)	24.2	(166.9)
Axial Fatigue (Transverse)						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	52.5	(362.0)			40.0	(275.8)
10^5 cycles, ksi (MPa)	29.0	(200.0)			30.0	(206.9)
10^7 cycles, ksi (MPa)	16.0	(110.3)			16.0	(110.3)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	38.5	(265.5)			38.5	(265.5)
10^5 cycles, ksi (MPa)	18.0	(124.1)			18.0	(124.1)
10^7 cycles, ksi (MPa)	10.0	(69.0)			10.0	(69.0)

Properties
Coefficient of Thermal Expansion
12.4 in./in./F x 10^{-6} (from RT to 212 F)
22.3 m/m K x 10^{-6} (from RT to 373 K)
Density
.098 lb./in.^{3} (2.71 g/cm^3)

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

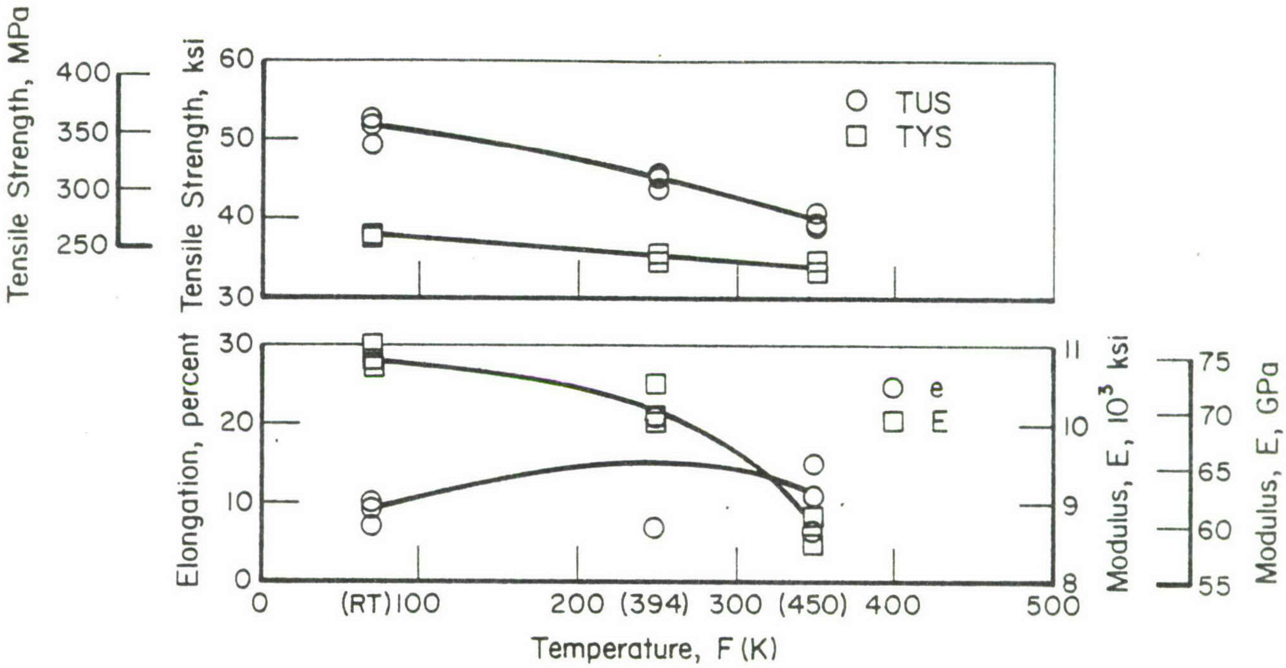


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF C355-T61 ALUMINUM CASTING

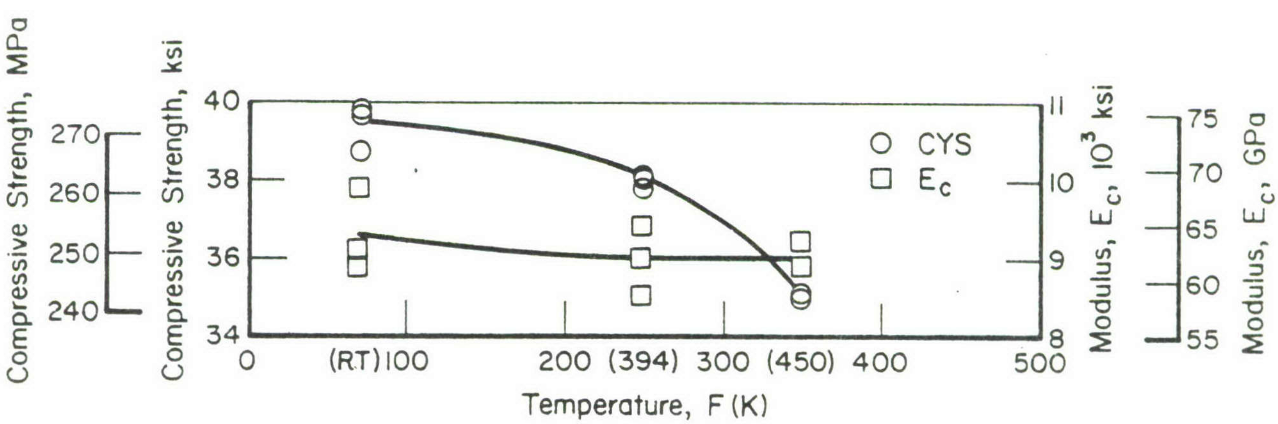


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF C355-T61 ALUMINUM CASTING

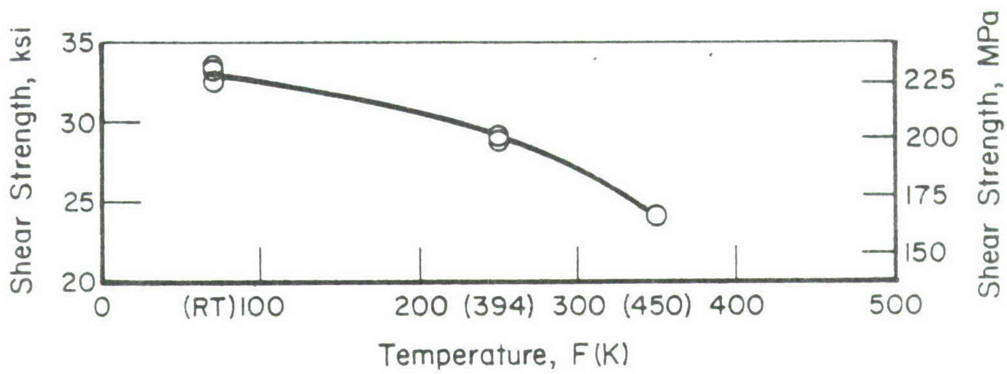


FIGURE 3. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF C355-T61 ALUMINUM CASTING

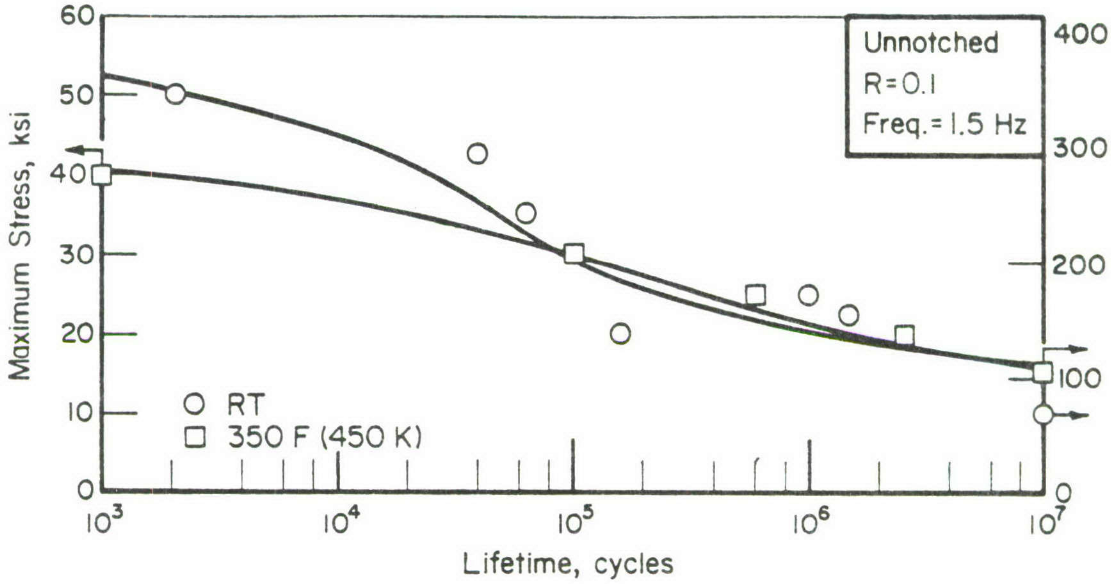


FIGURE 4. AXIAL LOAD BEHAVIOR OF UNNOTCHED C355-T61 ALUMINUM CASTING

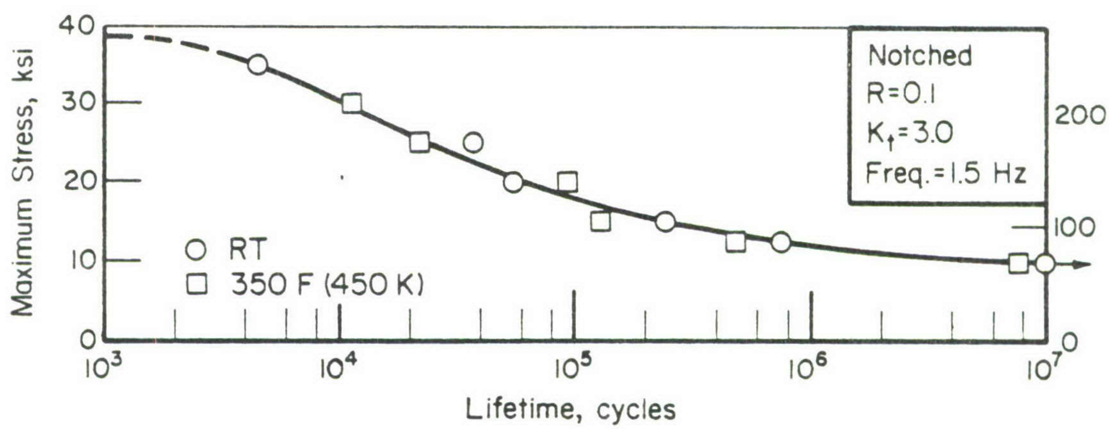


FIGURE 5. AXIAL LOAD BEHAVIOR OF NOTCHED C355-T61 ALUMINUM CASTING

Beta Processed Corona 5 Titanium Alloy

Material Description

Corona 5 is an alpha-beta alloy recently developed by Colt Industries and designed primarily for application in the aerospace industry. The development aim was for an alloy with toughness values above minimum required levels for fracture controlled titanium alloy parts.

The material evaluated was supplied GFM as 2-inch thick plate with the following composition:

Chemical Composition	Percent
Al	4.4
Mo	5.1
Cr	1.46
Fe	0.20
C	0.065
O_2	0.183
N_2	0.011
H_2	0.0018
Ti	Remainder

Processing and Heat Treating

The material was heat treated as follows: beta anneal 1525 F (1103 K), 4 hours, air cool plus age 1300 F (978 K), 6 hours, air cool.

Corona 5 Titanium Alloy[a]

Condition: Beta annealed and aged
Thickness: 2 inches

Properties	Temperature, F (K)					
	RT	(RT)	400	(477)	800	(700)
Tension						
TUS, L, ksi (MPa)	139.3	(960.5)	111.4	(768.1)	96.4	(664.5)
TUS, T, ksi (MPa)	140.3	(967.4)	115.1	(793.6)	96.4	(664.8)
TYS, L, ksi (MPa)	130.5	(900.0)	94.0	(647.9)	76.8	(529.5)
TYS, T, ksi (MPa)	132.5	(913.4)	98.4	(678.7)	79.3	(546.8)
e, L, percent in 1 in. (25.4 mm)	12.7		19.5		19.0	
e, T, percent in 1 in. (25.4 mm)	12.7		17.7		16.0	
RA, L, percent	17.0		47.5		62.7	
RA, T, percent	21.0		45.6		56.4	
E, L, 10^3 ksi (GPa)	16.0	(110.3)	16.3	(112.6)	12.9	(88.9)
E, T, 10^3 ksi (GPa)	16.8	(116.1)	16.1	(111.0)	13.8	(95.2)
Compression						
CYS, L, ksi (MPa)	138.4	(954.0)	97.2	(670.2)	78.3	(540.1)
CYS, T, ksi (MPa)	145.3	(1001.8)	102.0	(703.5)	82.9	(571.8)
E_c, L, 10^3 ksi (GPa)	17.0	(117.2)	14.8	(102.3)	13.4	(92.6)
E_c, T, 10^3 ksi (GPa)	17.2	(118.4)	15.2	(104.6)	13.7	(94.2)
Shear						
SUS, L, ksi (MPa)	89.7	(618.2)	75.1	(517.9)	62.5	(431.0)
SUS, T, ksi (MPa)	90.4	(623.6)	73.7	(508.2)	61.1	(421.4)
Bearing						
e/D = 1.5						
BUS, L, ksi (MPa)	224.5	(1547.7)	187.8	(1294.9)	161.0	(1110.1)
BUS, T, ksi (MPa)	226.4	(1560.8)	185.7	(1280.1)	162.3	(1119.1)
BYS, L, ksi (MPa)	201.1	(1386.4)	153.9	(1060.8)	130.2	(897.7)
BYS, T, ksi (MPa)	196.6	(1355.8)	154.6	(1065.6)	131.3	(905.3)
e/D = 2.0						
BUS, L, ksi (MPa)	283.5	(1954.5)	230.0	(1585.5)	208.7	(1438.6)
BUS, T, ksi (MPa)	291.8	(2012.0)	242.1	(1669.3)	204.9	(1412.4)
BYS, L, ksi (MPa)	233.5	(1609.8)	188.4	(1299.0)	155.1	(1069.4)
BYS, T, ksi (MPa)	240.1	(1655.5)	194.0	(1337.3)	155.3	(1070.4)
Fracture Toughness						
K_{Ic}, LT, ksi$\sqrt{in.}$ (MPa·$m^{\frac{1}{2}}$)	88.6	(97.4)[b]	U[c]		U	
K_{Ic}, TL, ksi$\sqrt{in.}$ (MPa·$m^{\frac{1}{2}}$)	92.1	(101.3)	U		U	

Properties	RT	(RT)	800	(700)
Axial Fatigue (Transverse)				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	105	(724)	100	(690)
10^5 cycles, ksi (MPa)	88	(607)	82	(565)
10^7 cycles, ksi (MPa)	85	(586)	76	(524)
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	95	(655)	90	(621)
10^5 cycles, ksi (MPa)	23	(159)	23	(159)
10^7 cycles, ksi (MPa)	12	(83)	16	(110)
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi (MPa)	NA(c)		24	(165)
0.2% plastic deformation, 1000 hr, ksi (MPa)	NA		11	(76)
Stress Rupture (Transverse)				
Rupture, 100 hr, ksi (MPa)	NA		92	(634)
Rupture, 1000 hr, ksi (MPa)	NA		72	(496)
Coefficient of Thermal Expansion				
6.1 in./in./F x 10^{-6} (RT - 800 F)				
(11.0 m/m K x 10^{-6} (RT - 700 K)				
Density				
0.164 lb/in.^{3}				
(4.539 g/cm^3)				

(a) Values are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress rupture values are from curves generated using the results of a greater number of tests.

(b) Through strict interpretation of ASTM E-399 the K_{Ic} values presented are not valid due to P_{max}/P_Q ratio; however, they are indicative of a tough material.

(c) U, unavailable; NA, not applicable.

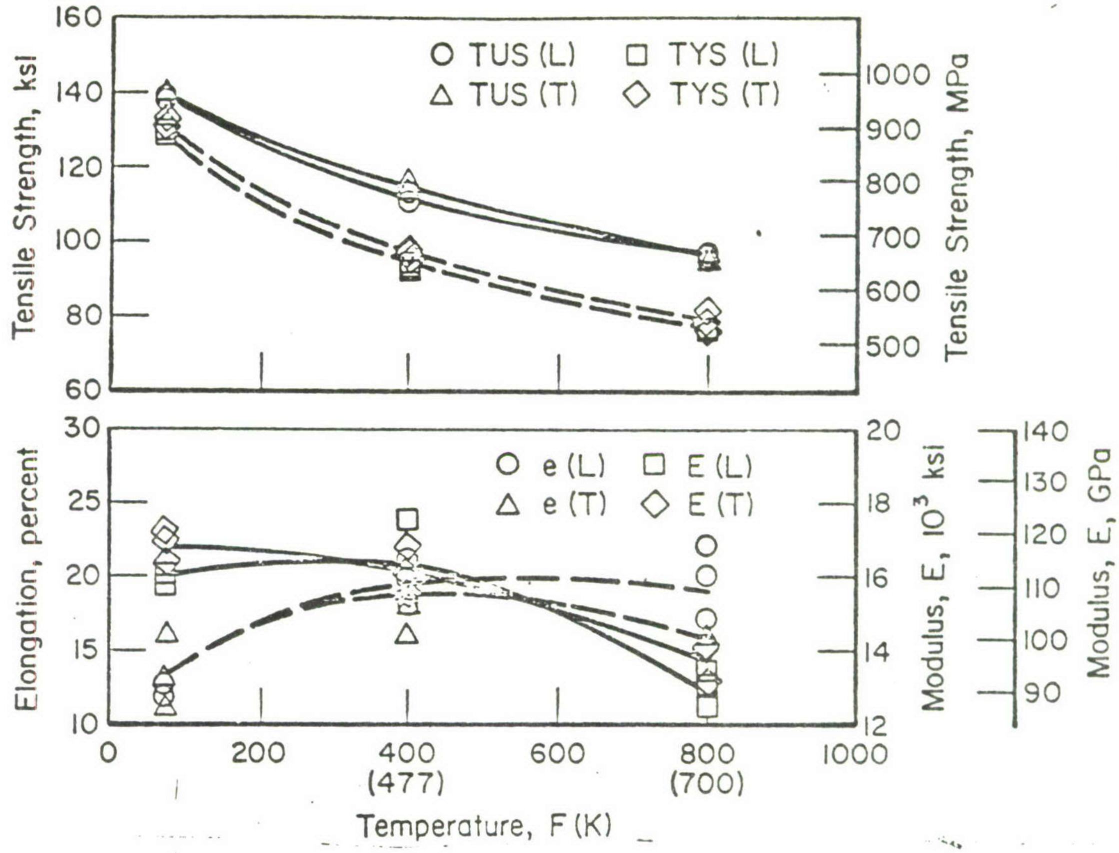


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA PROCESSED CORONA 5 TITANIUM ALLOY

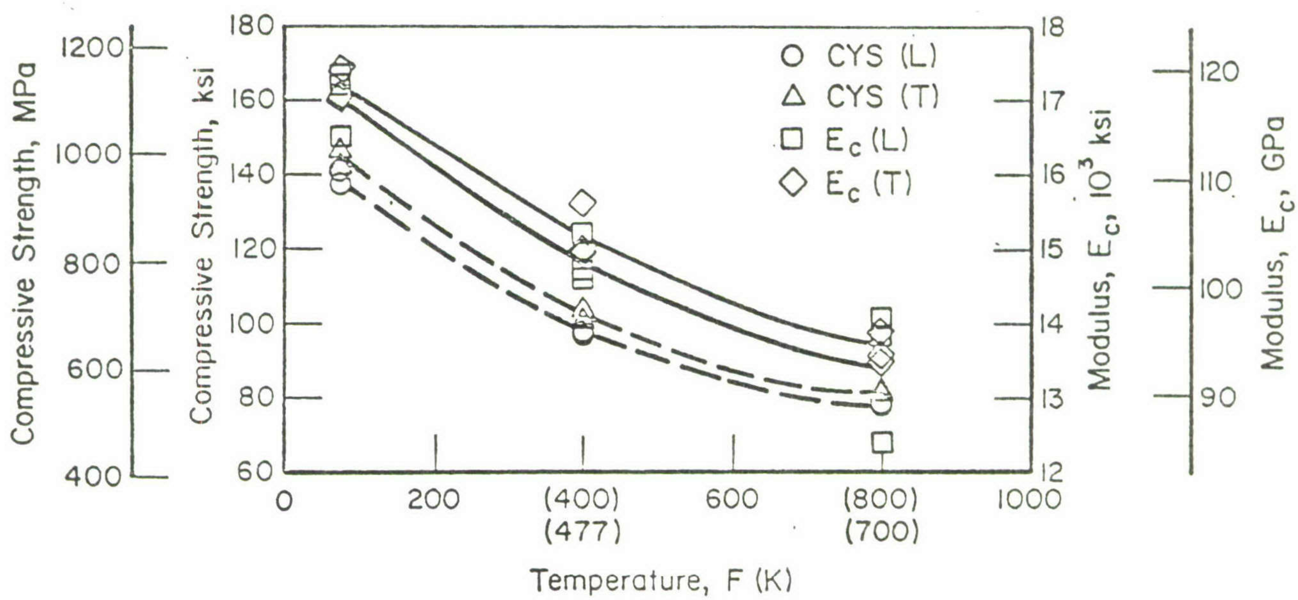


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF BETA PROCESSED CORONA 5 TITANIUM ALLOY

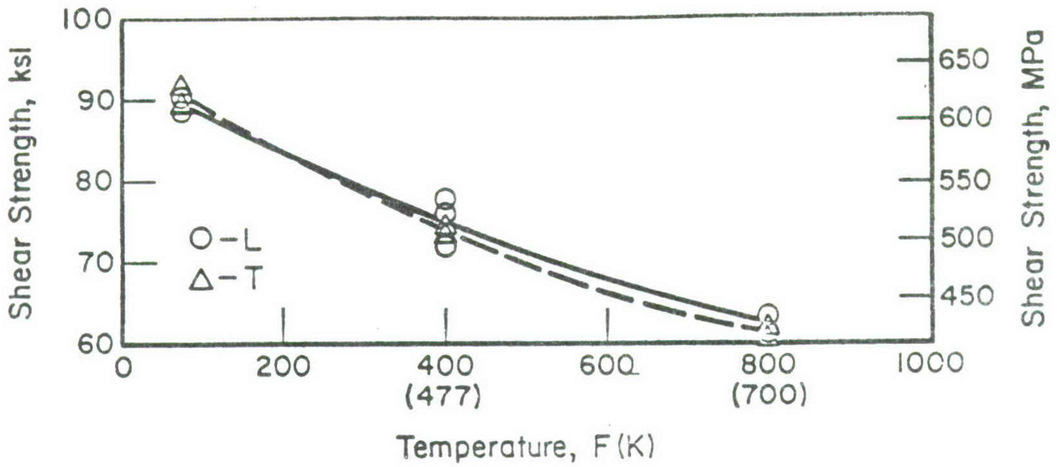


FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF BETA PROCESSED CORONA 5 TITANIUM ALLOY

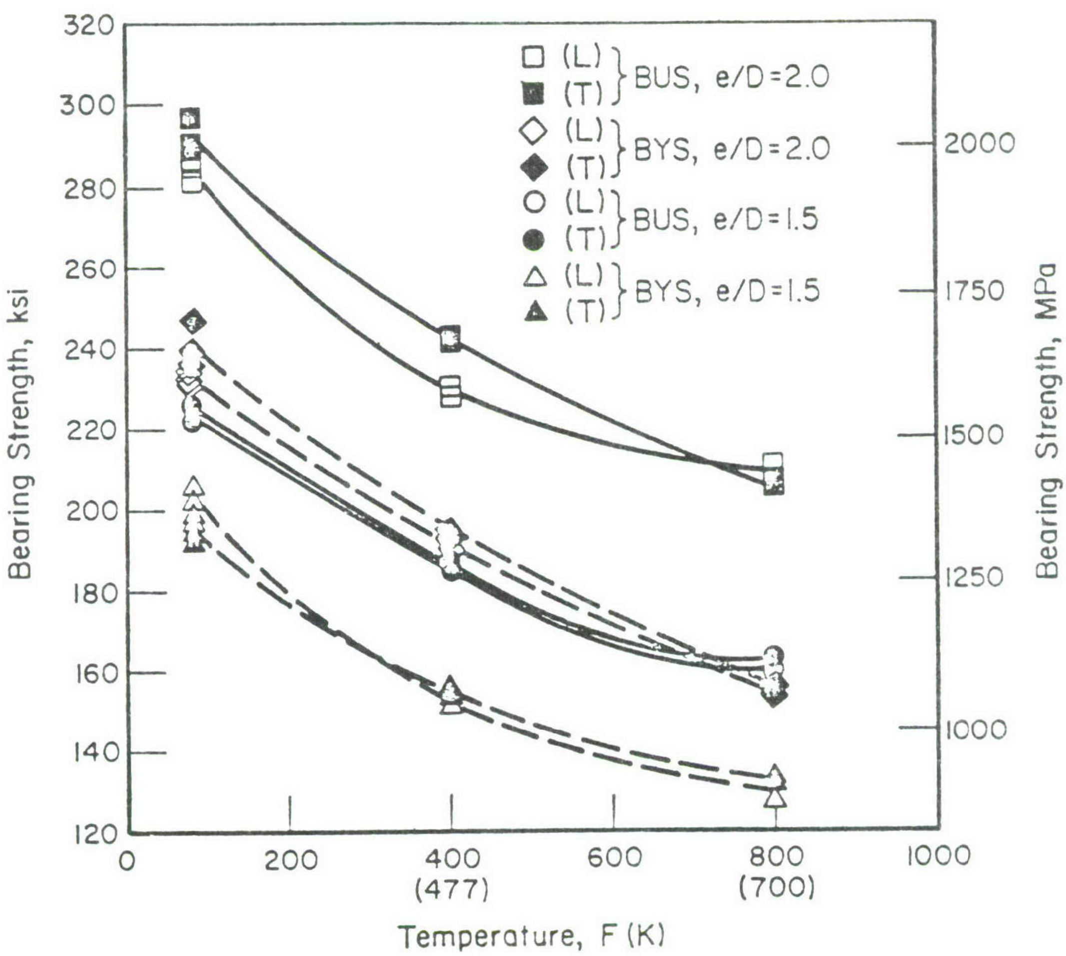


FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF BETA PROCESSED CORONA 5 TITANIUM ALLOY

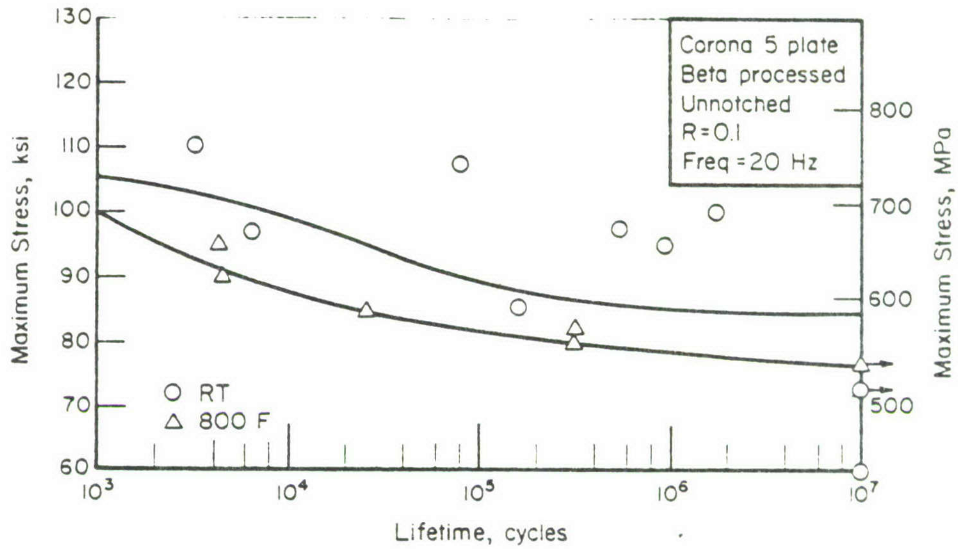


FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED BETA PROCESSED CORONA 5 TITANIUM ALLOY

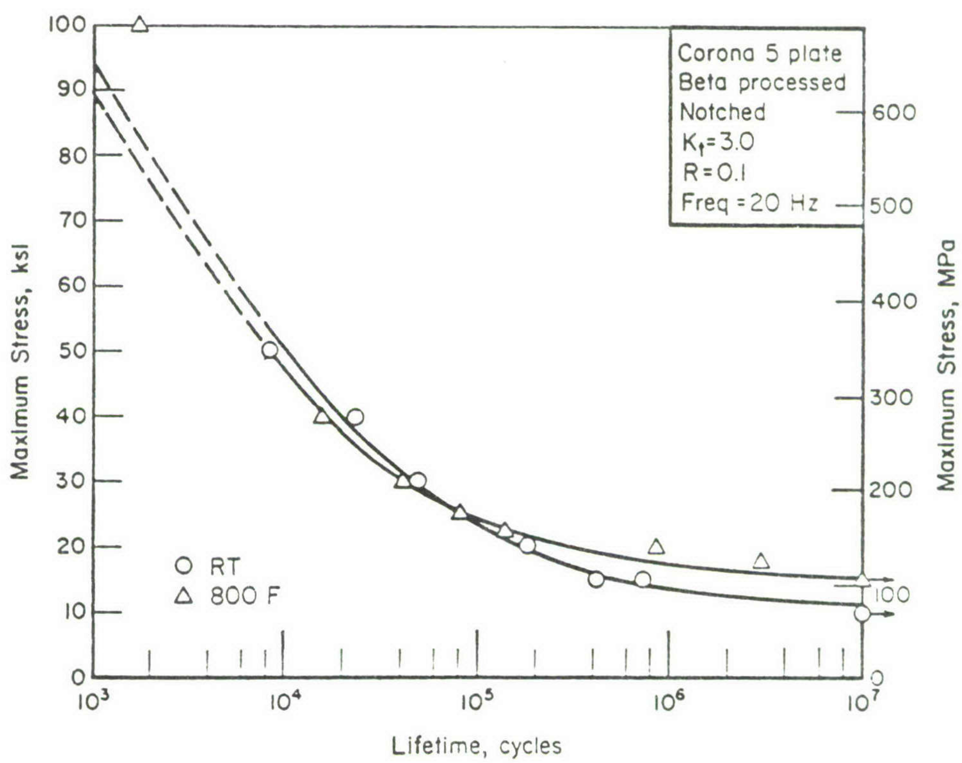


FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) BETA PROCESSED CORONA 5 TITANIUM ALLOY

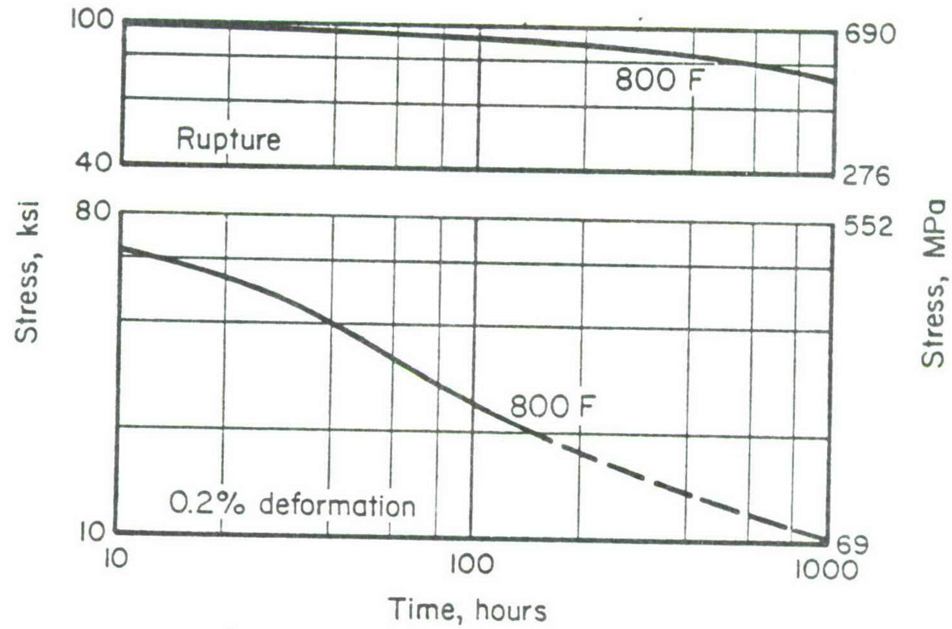


FIGURE 7. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR BETA PROCESSED CORONA 5 TITANIUM ALLOY

APPENDIX

SUPPORTING DATA GENERATED ON
Contract F33615-77-C-5009

Custom 450 Alloy

Material Description

Custom 450 is a multiple-strength heat-treatable stainless steel. The alloy was developed by Carpenter to meet the need for an alloy with the corrosion resistance of Type 304 stainless and with an annealed strength close to 100 ksi (689.5 MPa).

The Custom 450 strip used in this evaluation was 0.040-inch (1.016 mm) thick, with Carpenter Heat Number 825980. Strip form was chosen due to availability. The alloy was supplied in the solution-annealed state. The composition was as follows:

Chemical Composition	Percent
C	.028
Mn	.33
Si	.42
P	.026
S	.001
Cr	14.95
Ni	6.44
Mo	.79
Cu	1.50
Cb	.70

Processing and Heat Treating

Specimens were heat treated to the H 900 condition. This consists of aging at 900 F (755 K), for 4 (four) hours and air cooled. This heat treatment and the elevated temperatures chosen for evaluation were selected to reinforce data approved for use in MIL-HDBK-5.* The specimen layout is shown in Figure 1.

Test Results

Tension. Test results for both longitudinal and transverse specimens at room temperature, 400 F (477 K) and 800 F (700 K) are given in Table 1. Typical stress-strain curves at temperature are presented in Figures 2 and 3. Effect-of-temperature curves are presented in Figure 8.

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* Approved at the 51st Meeting, Item No. 75-23.

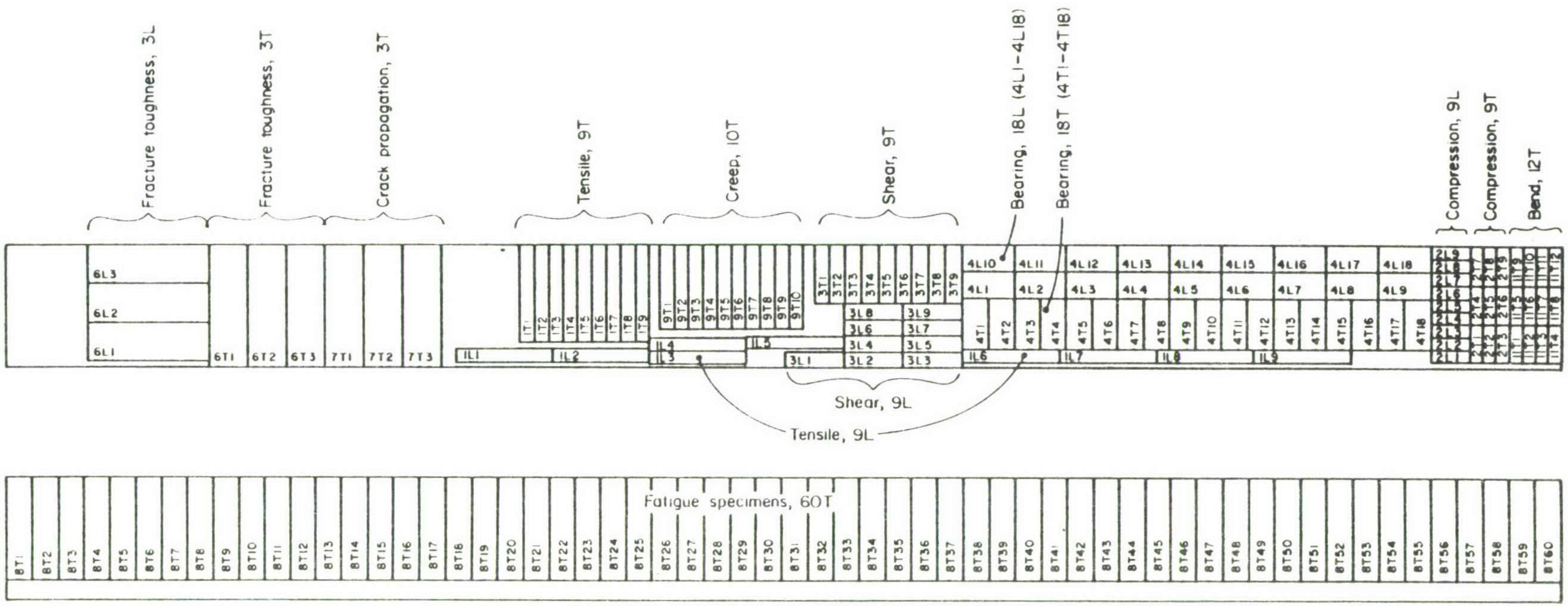

FIGURE 1. SPECIMEN LAYOUT FOR CUSTOM 450 STAINLESS STEEL STRIP

Compression. Tests were conducted at room temperature, 400 F (477 K), and 800 F (700 K) on both longitudinal and transverse specimens. Test results are given in Table 2. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 4 through 7. Effect-of-temperature curves are shown in Figure 9.

Shear. Tests were conducted at room temperature, 400 F (477 K), and 800 F (700 K) on both longitudinal and transverse specimens. Test results are given in Table 3. Effect-of-temperature curves are shown in Figure 10.

Bearing. Tests were conducted at room temperature, 400 F (477 K), and 800 F (700 K) on both longitudinal and transverse specimens. Test results are given in Table 4. Effect-of-temperature curves are presented in Figure 11.

Fracture Toughness. Results of center notch type specimen tests for both longitudinal and transverse directions are given in Table 5. Specimens were 0.04 inch (1.02 mm) thick and 2.00 inches (50.8 mm) wide with a span of 9 inches. The net section stress at fracture was greater than 80 percent of the tensile yield strength of the material, therefore the tests were not valid for determination of K_c. However, the two numbers are considered close enough to give an indication of the material toughness. Tests were done at room temperature only.

Crack Propagation. The data obtained are presented in Figure 12. The center notch type specimens were used. Tests were done at room temperature only.

Fatigue. Axial-load test results for transverse specimens at room temperature, 400 F (477 K), and 800 F (700 K) are given in Tables 6 and 7. These tests were conducted on both unnotched and notched (K_t = 3.0) specimens at a load ratio of R = 0.1. S-N curves are presented in Figures 13 and 14.

Creep and Stress-Rupture. Tests were conducted at 800 F (700 K) on transverse specimens. Tests results are given in Table 8. Log-stress versus log time curves are presented in Figure 15.

Bend. Tests were conducted at room temperature on transverse specimens 3 inches (76.2 mm) long, 1 inch (2.54 mm) wide and 0.04 inch (1.02 mm) thick. The minimum bend radius is 0.125 inch (3.12 mm).

Thermal Expansion. The coefficient of thermal expansion for this material is 6.37 in./in. F x 10^{-6} from RT to 800 F (11.47 cm/cm K x 10^{-5} from RT to 700 K).

Density. The density of this material is 0.28 lb./in^3 (7.75 g/cm^3).

TABLE 1. TENSILE TEST RESULTS FOR CUSTOM 450 STAINLESS STEEL

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 2 Inches (50.8 mm), percent	Tensile Modulus, 10^3 ksi	(GPa)
			Longitudinal at Room Temperature				
1L-1	195.6	(1348.7)	190.1	(1310.7)	6.5	30.0	(206.9)
1L-2	193.7	(1335.6)	193.4	(1333.5)	6.5	30.0	(206.9)
1L-3	196.1	(1352.1)	189.5	(1306.6)	7.5	30.8	(212.4)
Average	195.2	(1345.9)	191.0	(1316.9)	6.8	30.3	(208.9)
			Transverse at Room Temperature				
1T-1	199.0	(1372.1)	195.3	(1346.6)	6.0	29.8	(205.5)
1T-2	197.7	(1363.1)	192.6	(1328.0)	6.5	29.8	(205.5)
1T-3	199.1	(1372.8)	194.1	(1338.3)	6.0	31.0	(213.7)
Average	198.6	(1369.3)	194.0	(1337.6)	6.2	30.2	(208.2)
			Longitudinal at 400 F (477 K)				
1L-4	170.5	(1175.6)	162.1	(1117.7)	5.0	27.2	(187.5)
1L-5	171.6	(1183.2)	165.5	(1141.1)	5.0	26.0	(179.3)
1L-6	169.6	(1169.4)	161.1	(1110.8)	5.0	25.7	(177.2)
Average	170.6	(1176.3)	162.9	(1123.2)	5.0	26.3	(181.3)
			Transverse at 400 F (477 K)				
1T-4	173.4	(1195.6)	166.1	(1145.3)	5.0	27.8	(191.7)
1T-5	172.5	(1189.4)	165.4	(1140.4)	5.0	27.0	(186.2)
1T-6	171.8	(1184.6)	163.2	(1125.3)	5.0	26.7	(184.1)
Average	172.6	(1190.1)	164.9	(1137.0)	5.0	27.2	(187.5)
			Longitudinal at 800 F (700 K)				
1L-7	149.3	(1029.4)	135.8	(936.3)	6.5	23.8	(164.1)
1L-8	148.0	(1020.5)	132.5	(913.6)	5.5	23.9	(164.8)
1L-9	148.6	(1024.6)	133.9	(923.2)	6.0	24.6	(169.6)
Average	148.6	(1024.6)	133.7	(921.9)	6.0	24.1	(166.2)
			Transverse at 800 F (700 K)				
1T-7	149.6	(1031.5)	134.1	(924.6)	6.0	24.1	(166.2)
1T-8	151.6	(1045.3)	136.3	(939.8)	6.0	24.4	(168.2)
1T-9	151.1	(1041.8)	136.0	(937.7)	5.5	24.5	(168.9)
Average	150.8	(1039.8)	135.5	(934.3)	5.8	24.3	(167.5)

TABLE 2. COMPRESSION TEST RESULTS FOR CUSTOM 450 STAINLESS STEEL

Specimen Number	0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(GPa)
Longitudinal at Room Temperature				
2L-1	204.9	(1412.8)	31.7	(218.6)
2L-2	204.0	(1406.6)	31.9	(220.0)
2L-3	205.0	(1413.5)	32.2	(222.0)
Average	204.6	(1410.7)	31.9	(220.0)
Transverse at Room Temperature				
2T-1	208.9	(1440.4)	32.4	(223.4)
2T-2	207.5	(1430.7)	32.3	(222.7)
2T-3	209.9	(1447.3)	33.0	(227.5)
Average	208.8	(1439.7)	32.6	(224.8)
Longitudinal at 400 F (477 K)				
2L-4	179.7	(1239.0)	29.2	(201.3)
2L-5	178.7	(1232.1)	29.3	(202.0)
2L-6	178.3	(1229.4)	28.9	(199.3)
Average	178.9	(1233.5)	29.1	(200.6)
Transverse at 400 F (477 K)				
2T-4	180.1	(1241.8)	31.3	(215.8)
2T-5	179.6	(1238.3)	31.7	(218.6)
2T-6	181.8	(1253.5)	31.2	(215.1)
Average	180.5	(1244.5)	31.4	(216.5)
Longitudinal at 800 F (700 K)				
2L-7	149.0	(1027.4)	28.3	(195.1)
2L-8	152.2	(1049.4)	28.1	(193.7)
2L-9	150.0	(1034.3)	27.7	(191.0)
Average	150.4	(1037.0)	28.0	(193.1)
Transverse at 800 F (700 K)				
2T-7	150.8	(1039.8)	28.8	(198.3)
2T-8	150.8	(1039.8)	28.8	(198.3)
2T-9	153.0	(1054.9)	29.1	(200.6)
Average	151.5	(1044.6)	28.9	(199.3)

TABLE 3. SHEET SHEAR TEST RESULTS FOR CUSTOM 450 STAINLESS STEEL

Specimen Number		Ultimate Shear Strength, ksi	(MPa)
Longitudinal at Room Temperature			
3L-1		128.9	(888.8)
3L-2		127.4	(878.4)
3L-3		126.5	(872.2)
	Average	127.6	(879.8)
Transverse at Room Temperature			
3T-1		127.3	(877.7)
3T-2		124.4	(857.7)
3T-3		127.6	(879.8)
	Average	126.4	(871.5)
Longitudinal at 400 F (477 K)			
3L-4		109.9	(757.8)
3L-5		110.7	(763.3)
3L-6		107.7	(742.6)
	Average	109.4	(754.3)
Transverse at 400 F (477 K)			
3T-4		110.3	(760.5)
3T-5		106.0	(730.9)
3T-6		106.6	(735.0)
	Average	L07.6	(741.9)
Longitudinal at 800 F (700 K)			
3L-7		93.3	(643.3)
3L-8		92.4	(637.1)
3L-9		89.6	(617.8)
	Average	91.8	(633.0)
Transverse at 800 F (700 K)			
3T-7		93.5	(644.7)
3T-8		90.7	(625.4)
3T-9		90.8	(626.1)
	Average	91.7	(632.3)

TABLE 4. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR CUSTOM 450 STAINLESS STEEL

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Bearing Yield Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
	Longitudinal at Room Temperature			
4L-1	320.6 (2210.5)	357.8 (2467.0)	258.6 (1783.0)	302.9 (2088.5)
4L-2	305.2 (2104.4)	352.9 (2433.2)	260.6 (1796.8)	307.2 (2118.1)
4L-3	301.5 (2078.8)	335.9 (2316.0)	257.1 (1772.7)	300.8 (2074.0)
Average	309.1 (2131.2)	348.9 (2405.7)	258.8 (1784.4)	303.6 (2093.3)
	Transverse at Room Temperature			
4T-1	301.7 (2080.2)	391.1 (2696.6)	260.4 (1795.5)	304.9 (2102.3)
4T-2	307.7 (2121.6)	348.8 (2405.0)	260.3 (1794.8)	303.8 (2094.7)
4T-3	301.0 (2075.4)	363.7 (2507.7)	258.4 (1781.7)	302.7 (2087.1)
Average	303.5 (2092.6)	367.9 (2536.7)	259.7 (1790.6)	303.8 (2094.7)
	Longitudinal at 400 F (477 K)			
4L-4	260.9 (1798.9)	329.9 (2274.7)	232.5 (1603.1)	273.1 (1883.0)
4L-5	259.8 (1791.3)	323.2 (2228.5)	236.8 (1632.7)	275.0 (1896.1)
4L-6	265.6 (1831.3)	315.8 (2177.4)	238.5 (1644.5)	280.5 (1934.0)
Average	262.1 (1807.2)	323.0 (2227.1)	235.9 (1626.5)	276.2 (1904.4)
	Transverse at 400 F (477 K)			
4T-4	257.9 (1778.2)	324.1 (2234.7)	233.0 (1606.5)	271.2 (1869.9)
4T-5	260.3 (1794.8)	289.8 (1998.2) *	235.7 (1625.2)	279.5 (1927.2)
4T-6	257.2 (1773.4)	343.0 (2365.0)	232.8 (1605.2)	274.6 (1893.4)
Average	258.5 (1782.4)	319.0 (2199.5)	233.8 (1612.1)	275.1 (1896.8)
	Longitudinal at 800 F (700 K)			
4L-7	227.0 (1565.2)	242.4 (1671.3)	208.0 (1434.2)	240.2 (1656.2)
4L-8	224.5 (1547.9)	285.1 (1965.8)	202.1 (1393.5)	239.1 (1648.6)
4L-9	221.4 (1526.6)	312.6 (2155.4)	199.2 (1373.5)	239.1 (1648.6)
Average	224.3 (1546.5)	280.0 (1930.6)	203.1 (1400.4)	239.5 (1651.4)
	Transverse at 800 F (700 K)			
4T-7	215.1 (1483.1)	303.4 (2091.9)	198.0 (1365.2)	231.3 (1594.8)
4T-8	220.3 (1519.0)	291.4 (2009.2)	201.4 (1388.7)	228.4 (1574.8)
4T-9	223.2 (1539.0)	301.6 (2079.5)	202.4 (1395.5)	235.2 (1621.7)
Average	219.5 (1513.5)	298.8 (2060.2)	200.6 (1383.1)	231.6 (1596.9)

* Loading hole elongated.

TABLE 5. FRACTURE TOUGHNESS TEST RESULTS FOR CUSTOM 450 STAINLESS STEEL STRIP AT ROOM TEMPERATURE

Specimen Number	Thickness, B, inch	(mm)	Width, w, inch	(mm)	Maximum Stress, ksi	(MPa)	Initial Precrack, inches	(mm)	Apparent SIF, K_c, $ksi\sqrt{in.}$	$(MPa \cdot m^{\frac{1}{2}})$	Net Section Stress, ksi	(MPa)
6-L2	.042	(1.07)	1.996	(50.70)	143.7	(988.0)	.4772	(12.12)	175.4	(193.0)	188.3	(1298.3)
6-L3	.042	(1.07)	1.996	(50.70)	145.1	(1000.5)	.4704	(11.95)	180.2	(198.3)	189.8	(1308.7)
Average					144.2	(994.2)			177.8	(195.6)	189.0	(1303.5)
6-T2	.042	(1.07)	1.996	(50.70)	138.7	(956.3)	.4765	(12.10)	231.7	(254.9)	182.2	(1256.3)
6-T3	.042	(1.07)	1.996	(50.70)	137.9	(950.8)	.5005	(12.71)	230.3	(253.4)	184.0	(1268.7)
Average					138.3	(953.6)			231.0	(254.1)	183.1	(1262.5)

TABLE 6. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED CUSTOM 450 STAINLESS STEEL STRIP AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-4	200.0	(1379.0)	3,700
8-3	180.0	(1241.1)	11,200
8-2	160.0	(1103.2)	22,700
8-4	140.0	(965.3)	41,700
8-5	130.0	(896.4)	46,600
8-6	120.0	(827.4)	61,500
8-27	110.0	(758.5)	90,100
8-7	100.0	(689.5)	231,600
8-21	95.0	(655.0)	10,045,000[a]
	400 F (477 K)		
8-13	180.0	(1241.1)	7,200
8-12	160.0	(1103.2)	15,900
8-11	140.0	(965.3)	29,300
8-26	130.0	(896.4)	41,700
8-14	120.0	(827.4)	63,400
8-25	110.0	(758.5)	121,900
8-28	105.0	(724.0)	89,900
8-30	100.0	(689.5)	37,500[b]
8-8	100.0	(689.5)	103,194[c]
8-15	95.0	(655.0)	10,235,000[a]
8-12	90.0	(620.6)	3,727,985[c]
	800 F (700 K)		
8-19	180.0	(1241.1)	(d)
8-24	170.0	(1172.2)	400
8-18	160.0	(1103.2)	7,300
8-23	150.0	(1034.3)	21,000
8-16	140.0	(965.3)	18,700
8-22	130.0	(896.4)	121,600
8-17	120.0	(827.4)	228,300[a]
8-20	120.0	(827.4)	3,937,800
8-29	115.0	(792.9)	10,000,000[a]

(a) Did not fail.
(b) Specimen was bent.
(c) Failed at thermocouple.
(d) Failed on first cycle.

TABLE 7. RESULTS OF AXIAL LOAD FATIGUE TEST FOR NOTCHED (K_t = 3.0) CUSTOM 450 STAINLESS STEEL AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-31	120.0	(827.4)	3,500
8-32	100.0	(689.5)	6,300
8-33	80.0	(551.6)	11,630
8-57	70.0	(482.7)	16,641
8-34	60.0	(413.7)	22,390
8-46	50.0	(344.8)	39,678
8-35	40.0	(275.8)	89,890
8-39	35.0	(241.3)	10,171,000 (a)
8-36	30.0	(206.9)	10,079,000 (a)
	400 F (477 K)		
8-42	120.0	(827.4)	3,700
8-41	100.0	(689.5)	6,300
8-40	80.0	(551.6)	12,500
8-58	70.0	(482.7)	16,041
8-44	60.0	(413.7)	6,000 (b)
8-45	60.0	(413.7)	26,400
8-47	50.0	(344.8)	49,100
8-48	45.0	(310.3)	56,000
8-43	40.0	(275.8)	10,000,000 (a)
	800 F (700 K)		
8-50	120.0	(827.4)	2,299
8-51	100.0	(689.5)	3,400
8-49	80.0	(551.6)	6,878
8-59	70.0	(482.7)	9,883
8-54	60.0	(413.7)	14,961
8-52	60.0	(413.7)	27,533 (c)
8-55	50.0	(344.8)	24,208
8-53	40.0	(275.8)	38,352
8-60	35.0	(241.3)	10,044,820 (a)
8-56	30.0	(206.9)	10,005,927 (a)

(a) Did not fail.
(b) Specimen bent.
(c) Counter ran after failure.

TABLE 8. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR CUSTOM 450 STAINLESS STEEL

Specimen Number	Stress, ksi (MPa)	Temperature, F (K)	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches (50.8 mm), percent	Minimum Creep Rate, percent/hour
			0.1	0.2	0.5	1.0	2.0				
9-4	155 (1069)	800 (700)	--	--	0.02	0.06	0.17	1.755	0.3	5.2	--
9-3	140 (965)	800 (700)	0.05	0.15	1.2	4.8	17.5	0.854	47.8	9.1	0.079
9-2	125 (862)	800 (700)	0.3	1.3	14	120	345	0.792	550.2	10.4	0.0028
9-5	120 (827)	800 (700)	0.6	4.0	65	385	855	0.639	1277.5	9.6	0.0012
9-1	100 (690)	800 (700)	11	80	1100	3400[a]	--	0.607	1103.4[b]	1.108	0.0020
9-6	85 (586)	800 (700)	60	375	5000[a]	--	--	0.378	1005.9[b]	0.646	0.00006

(a) Estimated.

(b) Test discontinued.

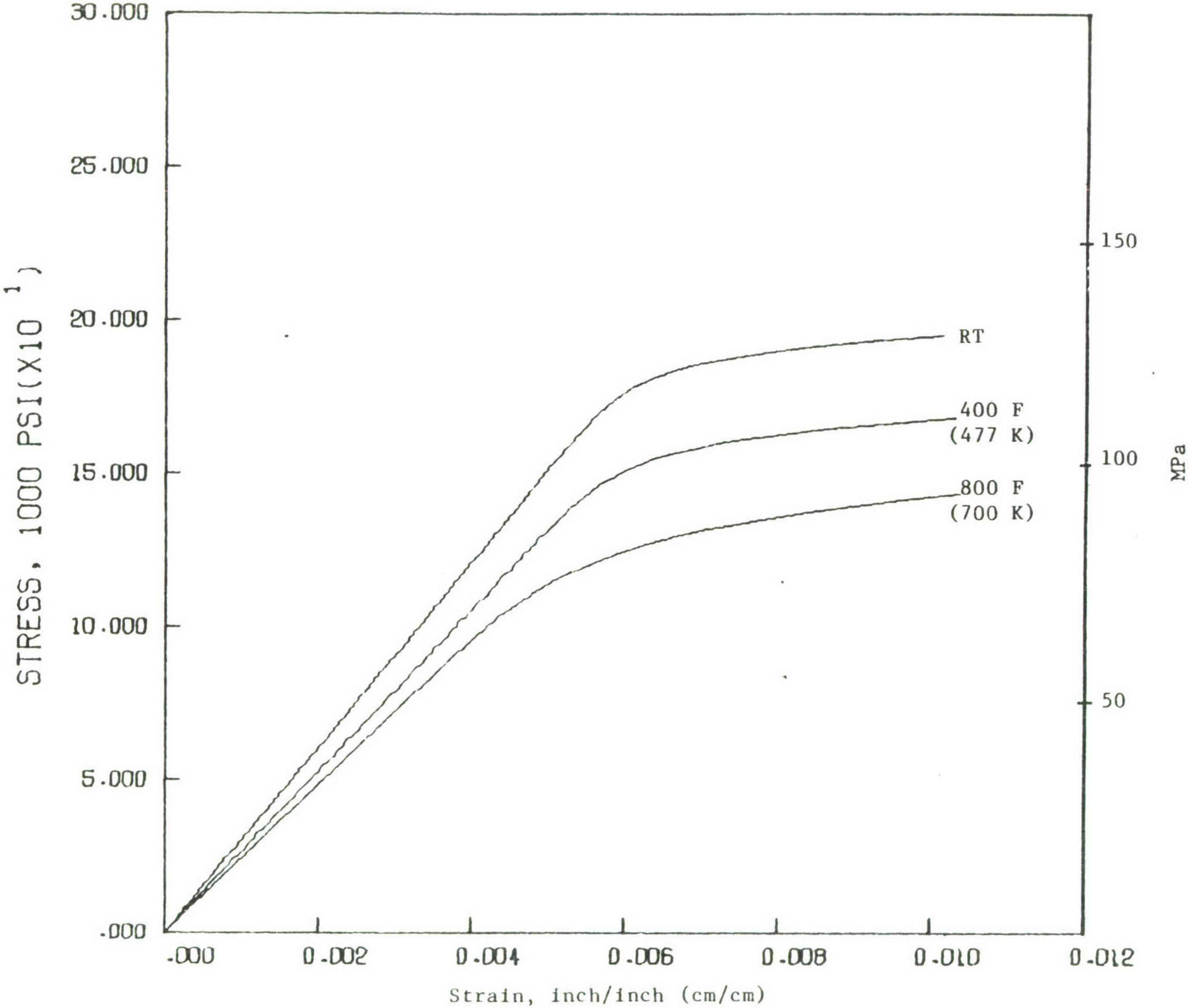

FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE (LONGITUDINAL)

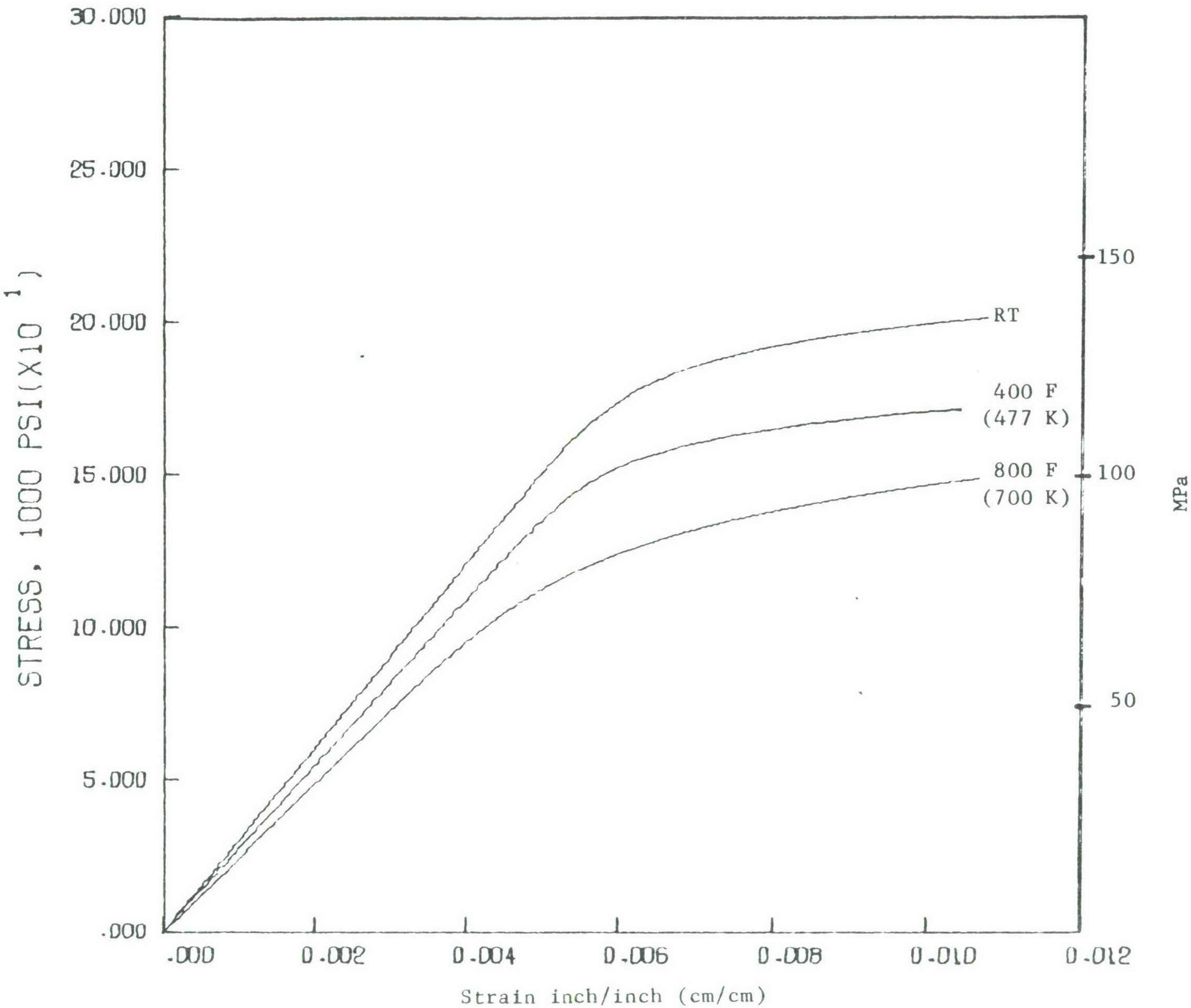

FIGURE 3. TYPICAL TENSILE STRESS-STRAIN CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE. (TRANSVERSE)

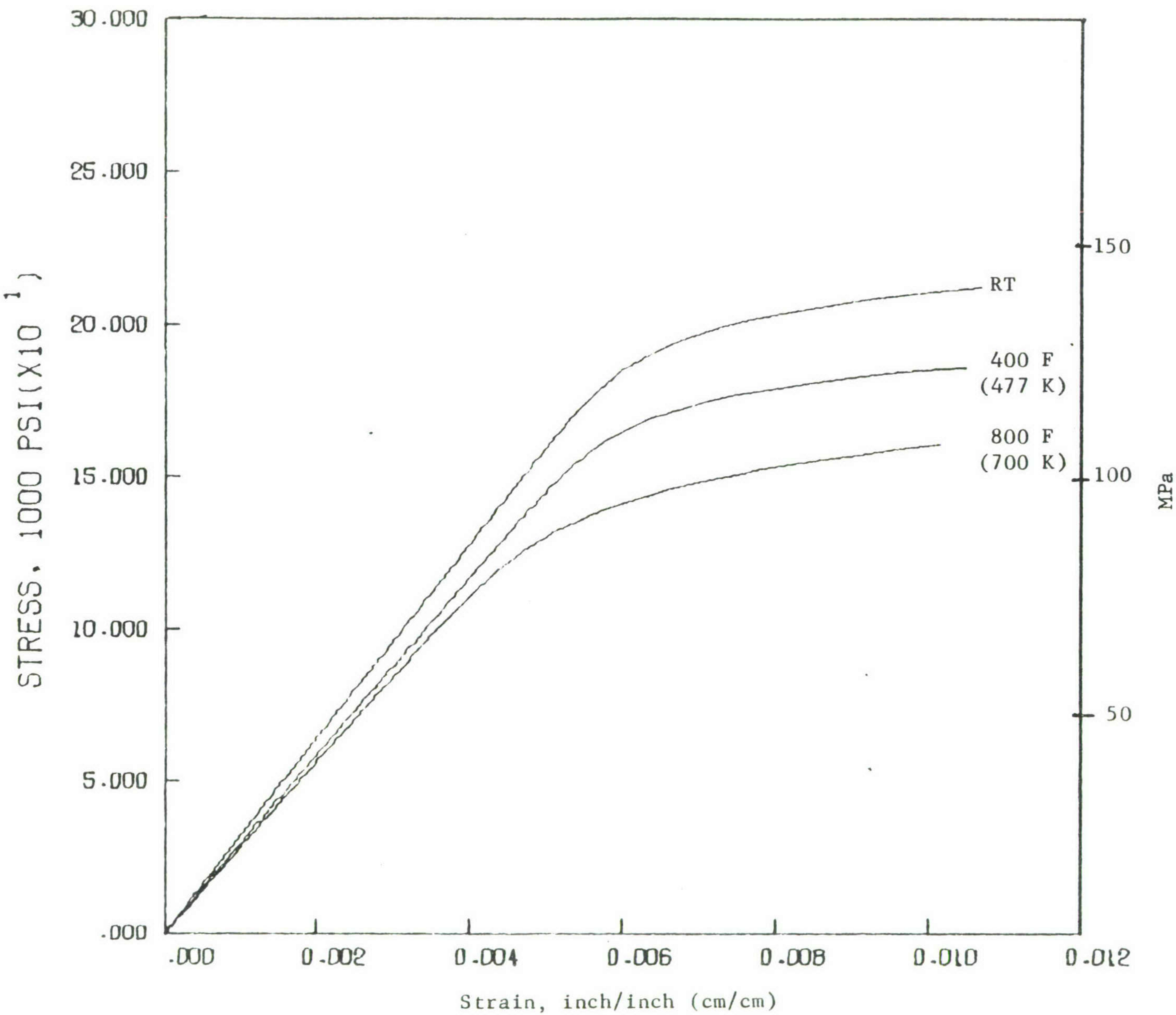

FIGURE 4. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE. (LONGITUDINAL)

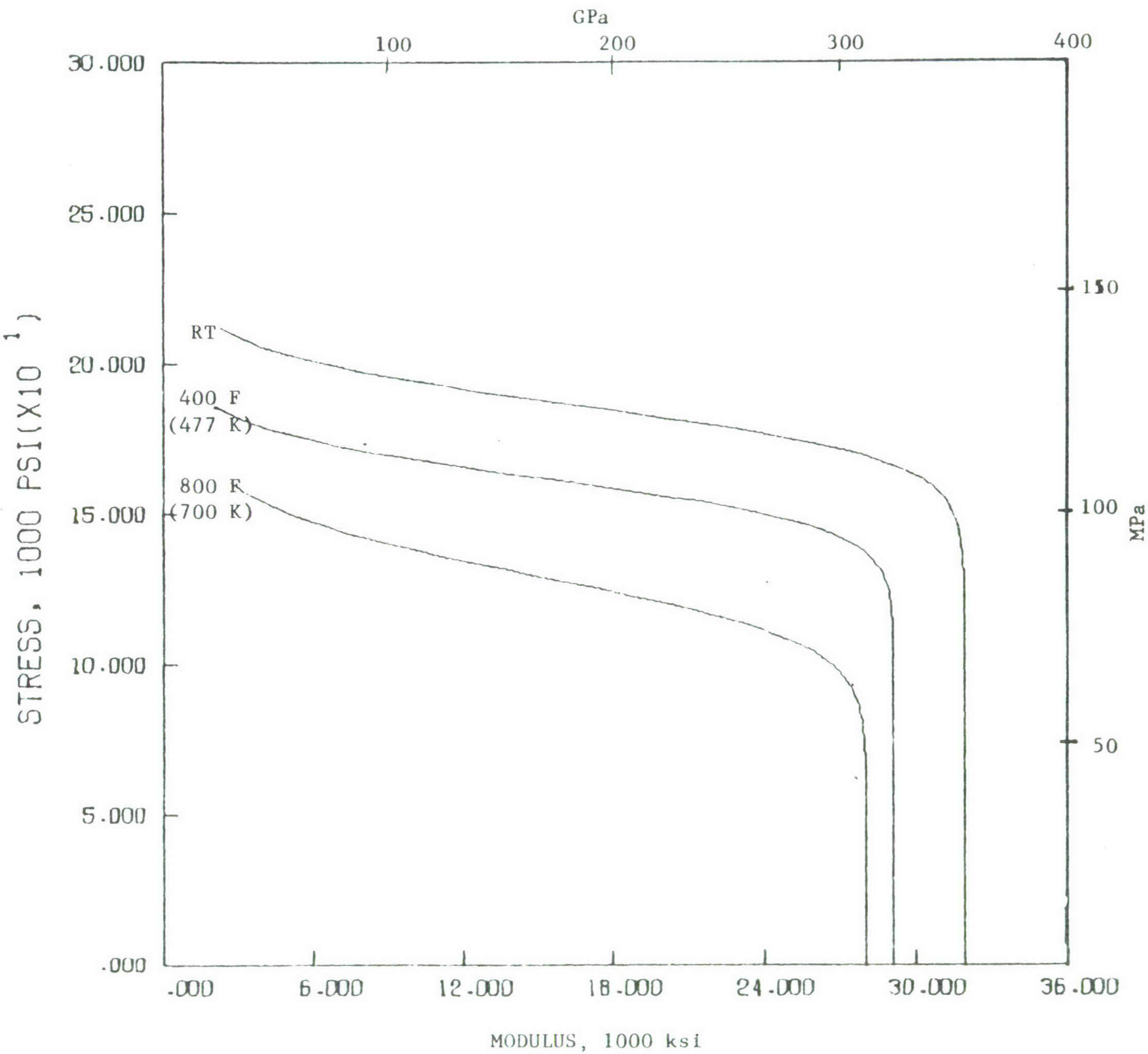

FIGURE 5. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE. (LONGITUDINAL)

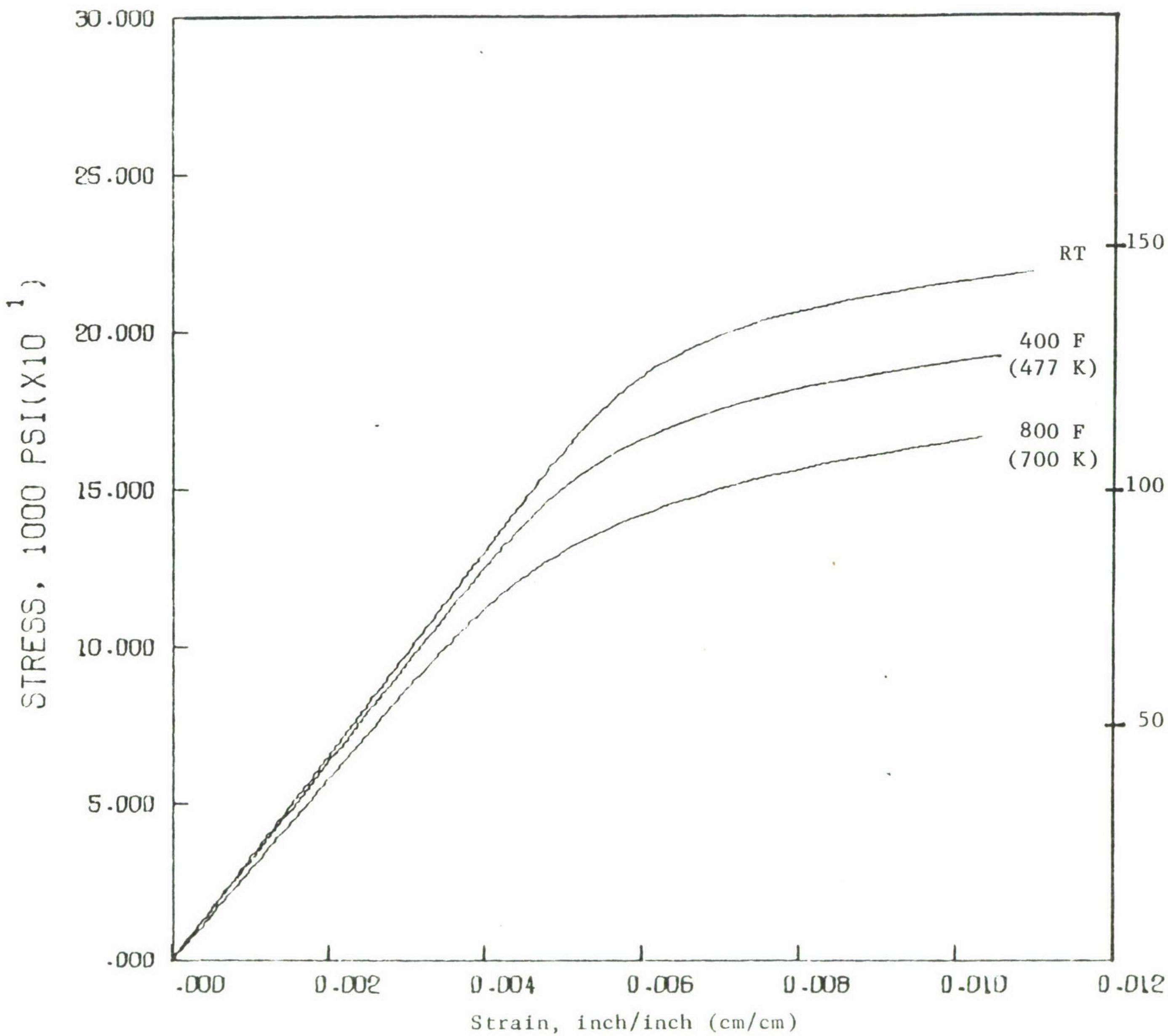

FIGURE 6. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE. (TRANSVERSE)

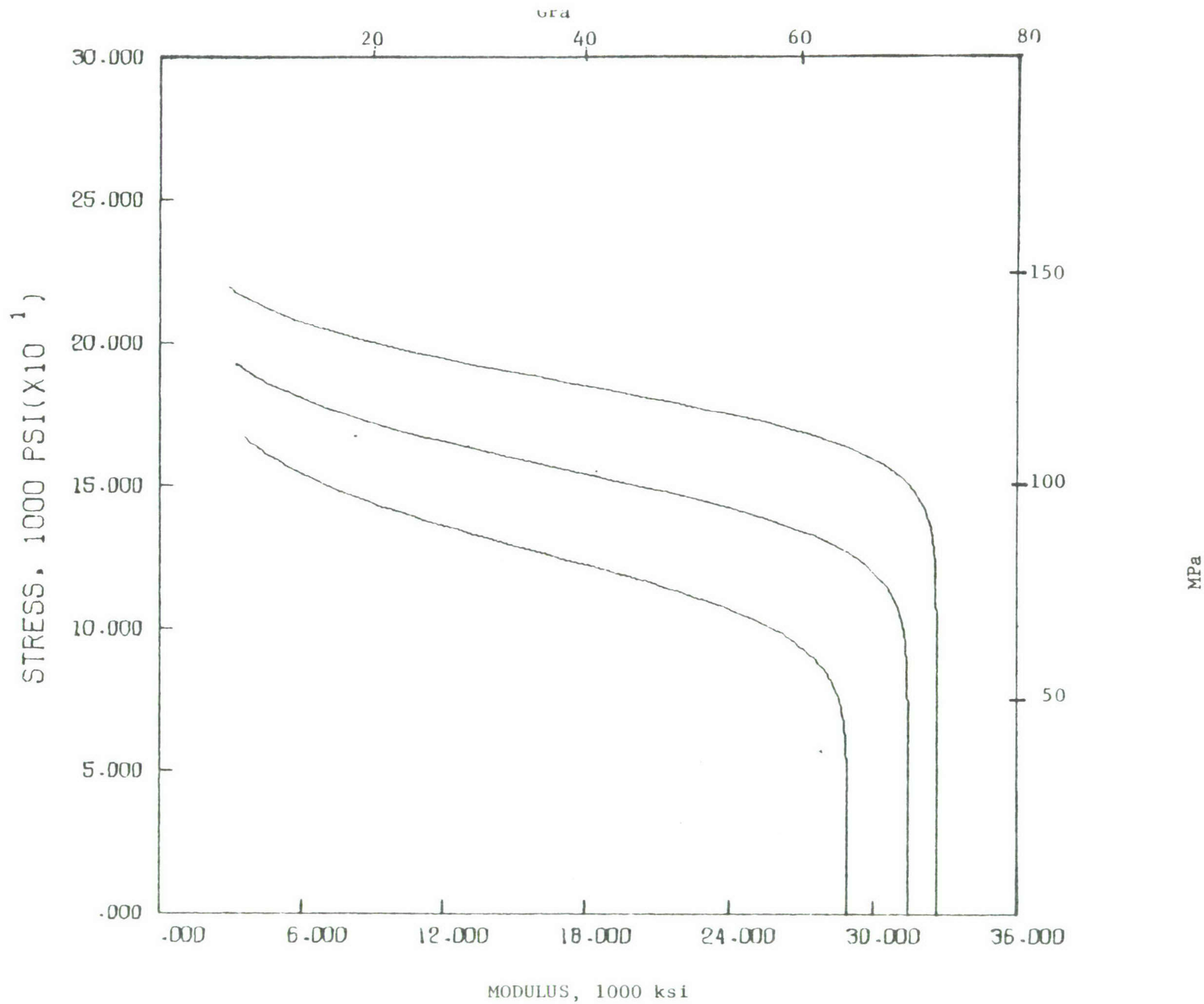

FIGURE 7. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP AT TEMPERATURE. (TRANSVERSE)

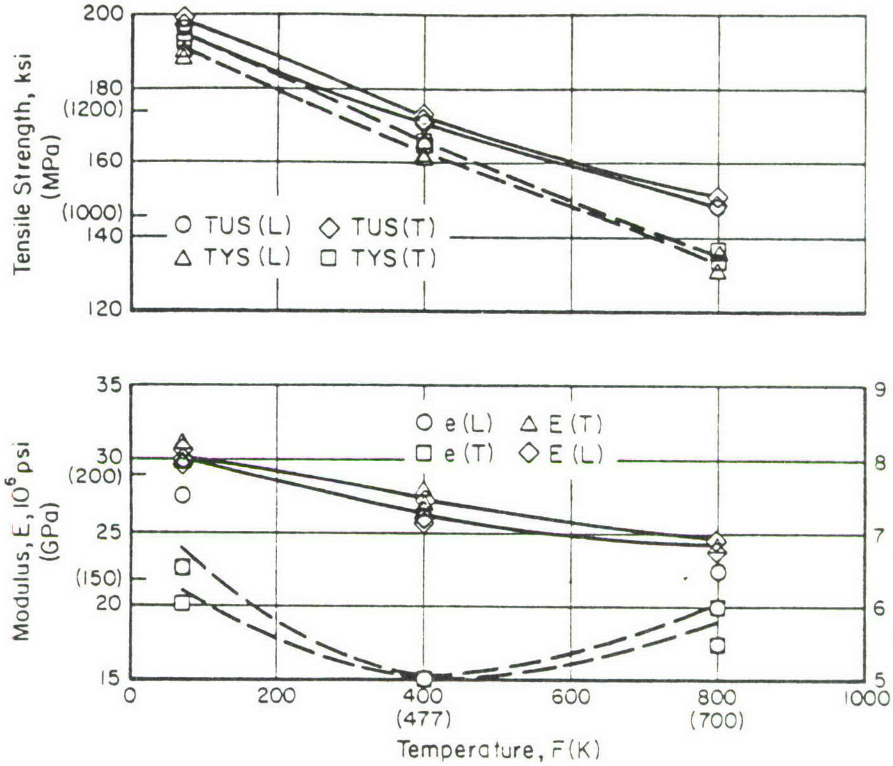

FIGURE 8. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CUSTOM 450 STAINLESS STEEL

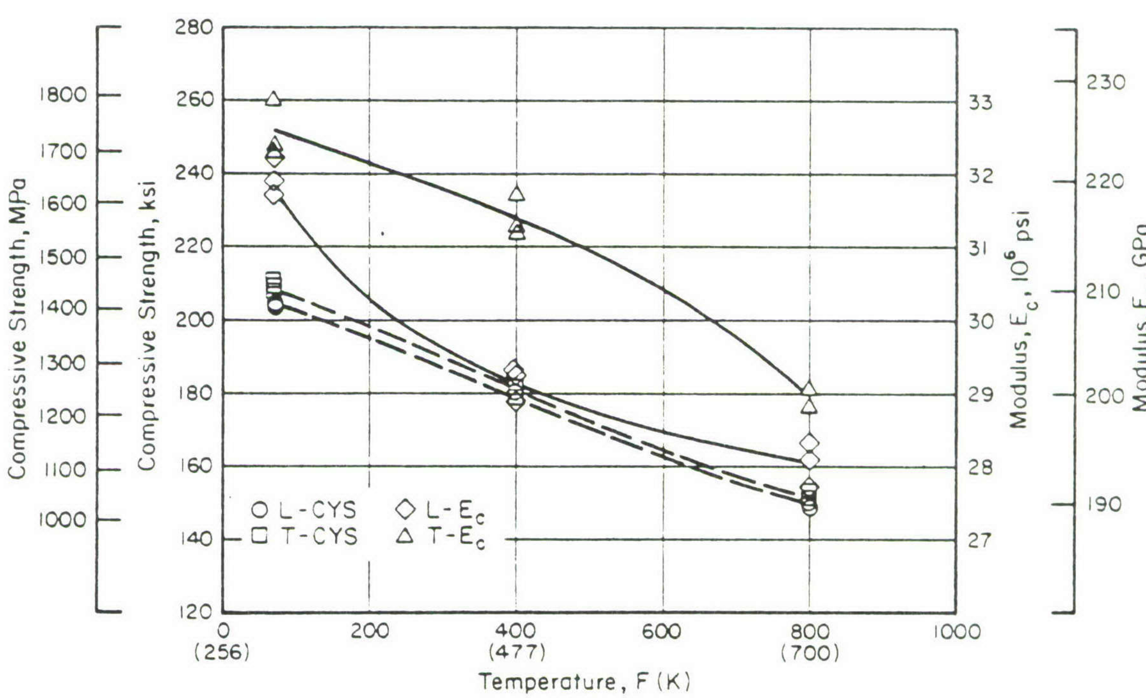

FIGURE 9. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF CUSTOM 450 STAINLESS STEEL

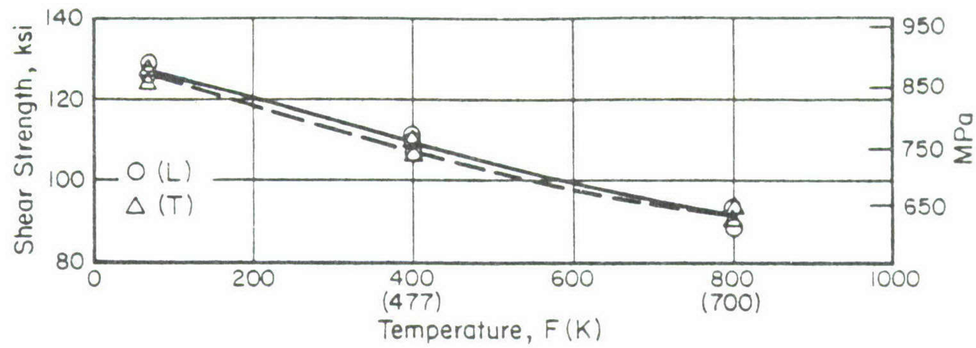

FIGURE 10. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF CUSTOM 450 STAINLESS STEEL

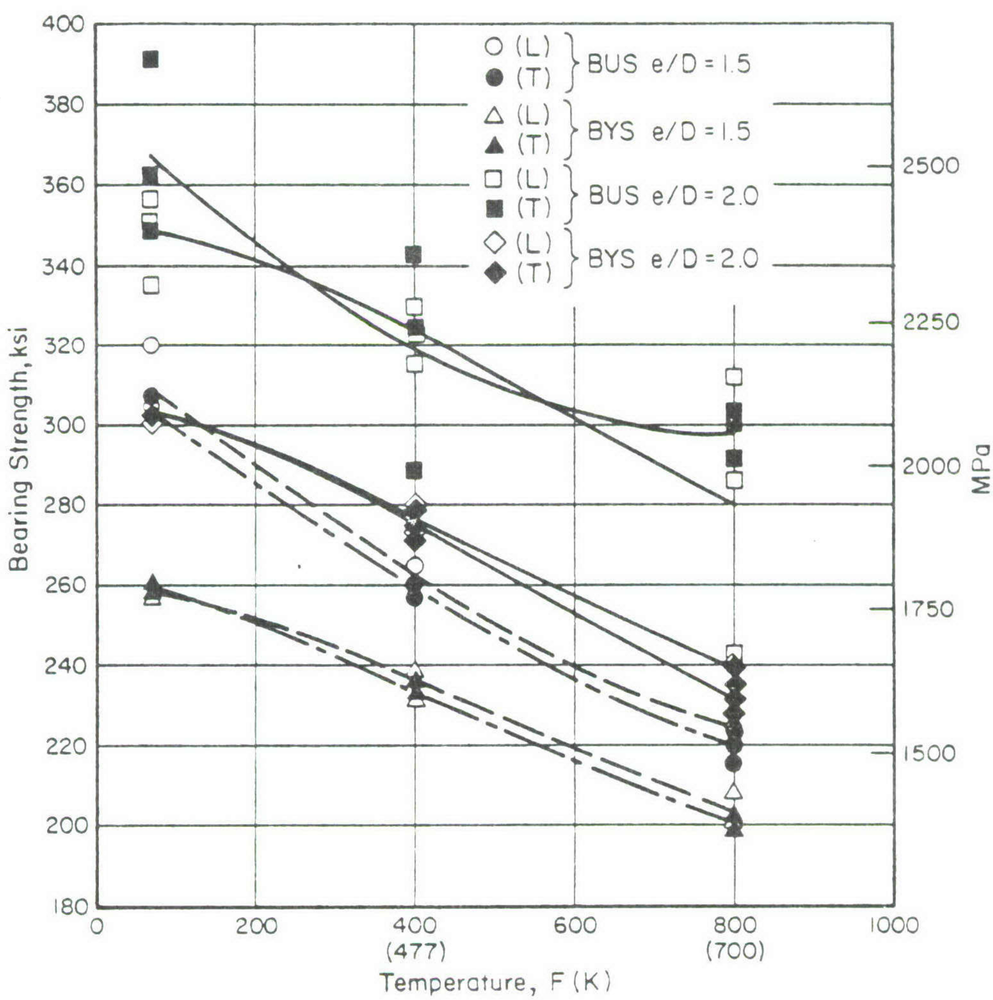

FIGURE 11. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF CUSTOM 450 STAINLESS STEEL

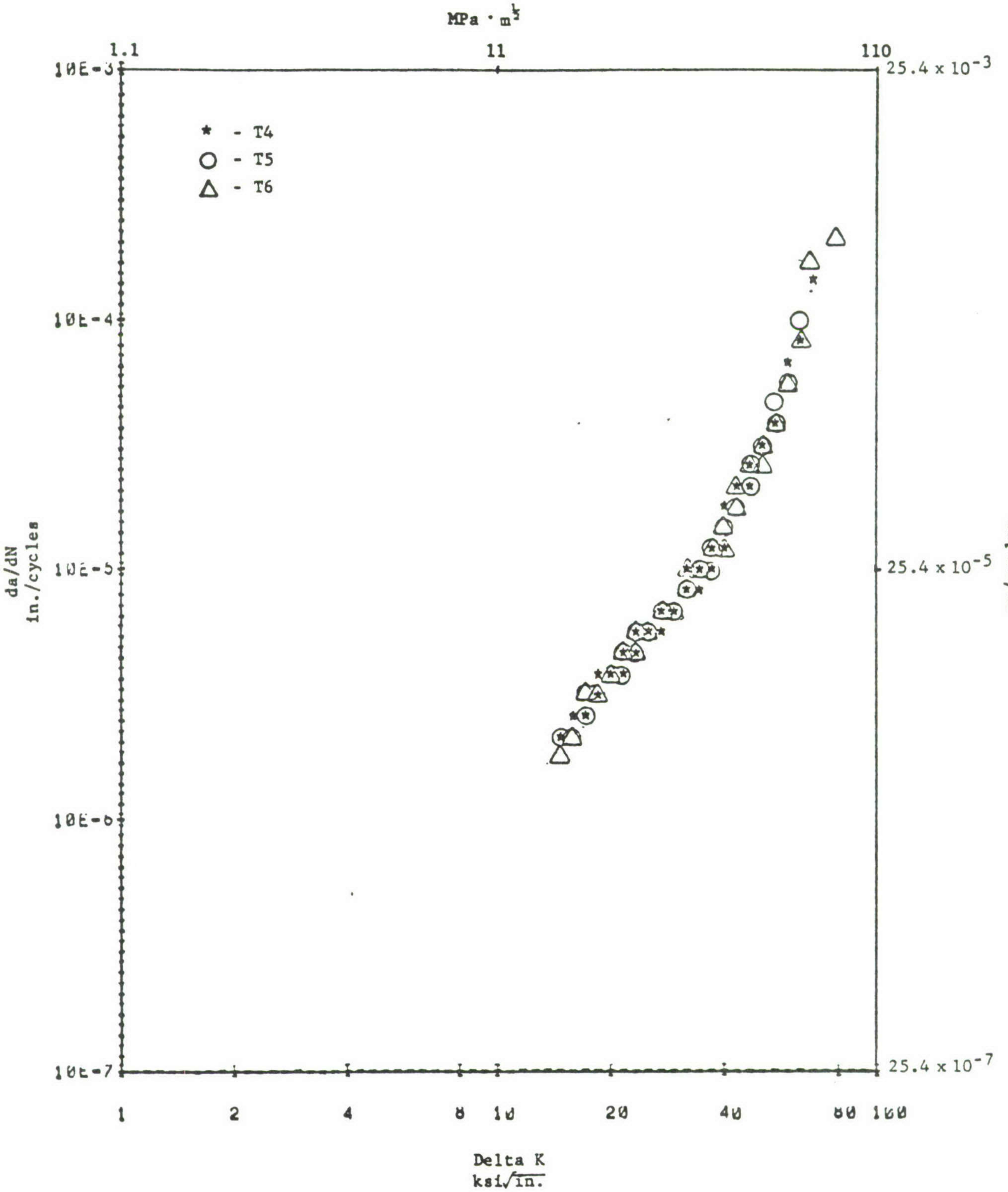

FIGURE 12. da/dN VERSUS DELTA K FOR CUSTOM 450 STAINLESS STEEL

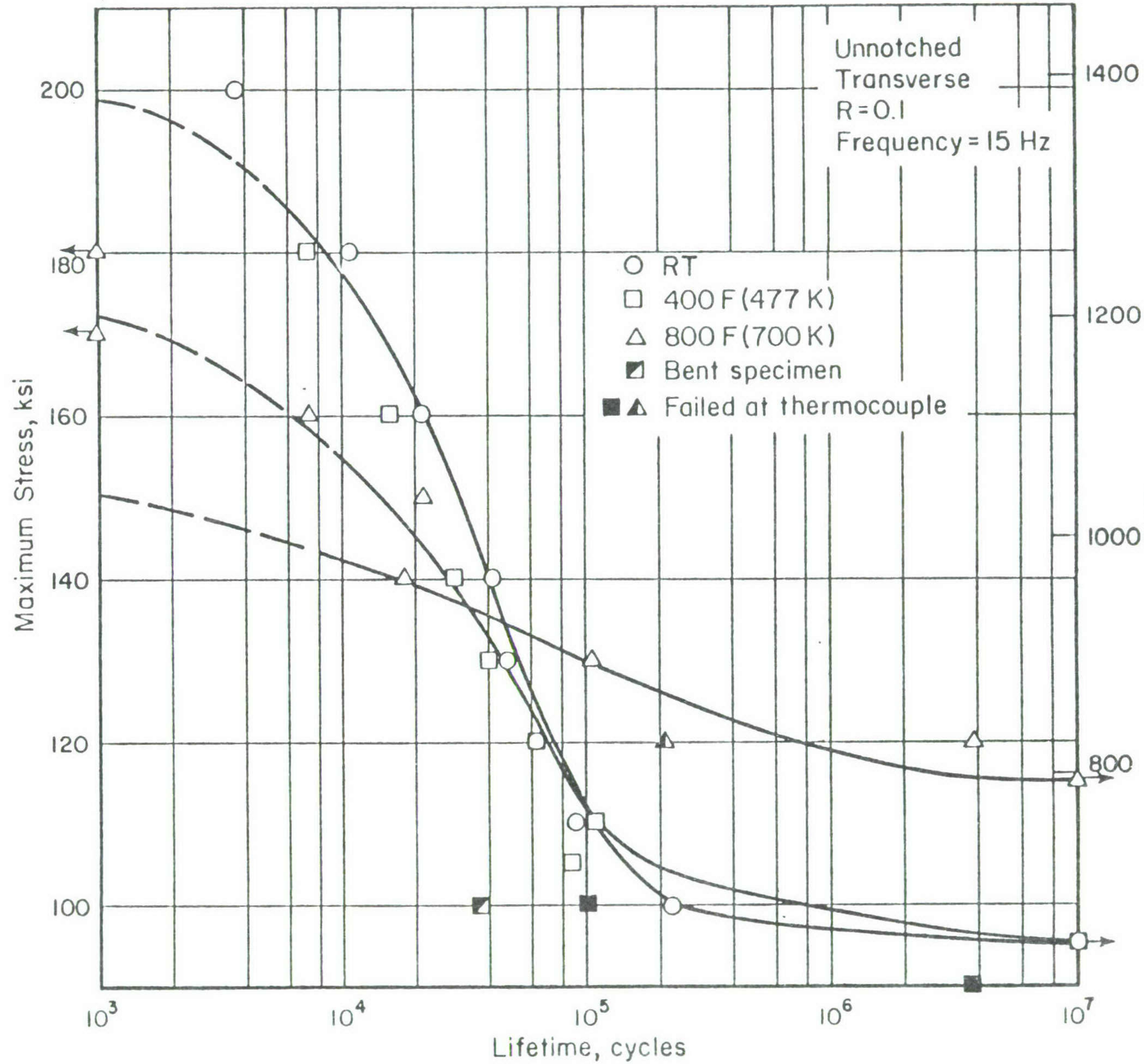

FIGURE 13. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED CUSTOM 450 STAINLESS STEEL STRIP

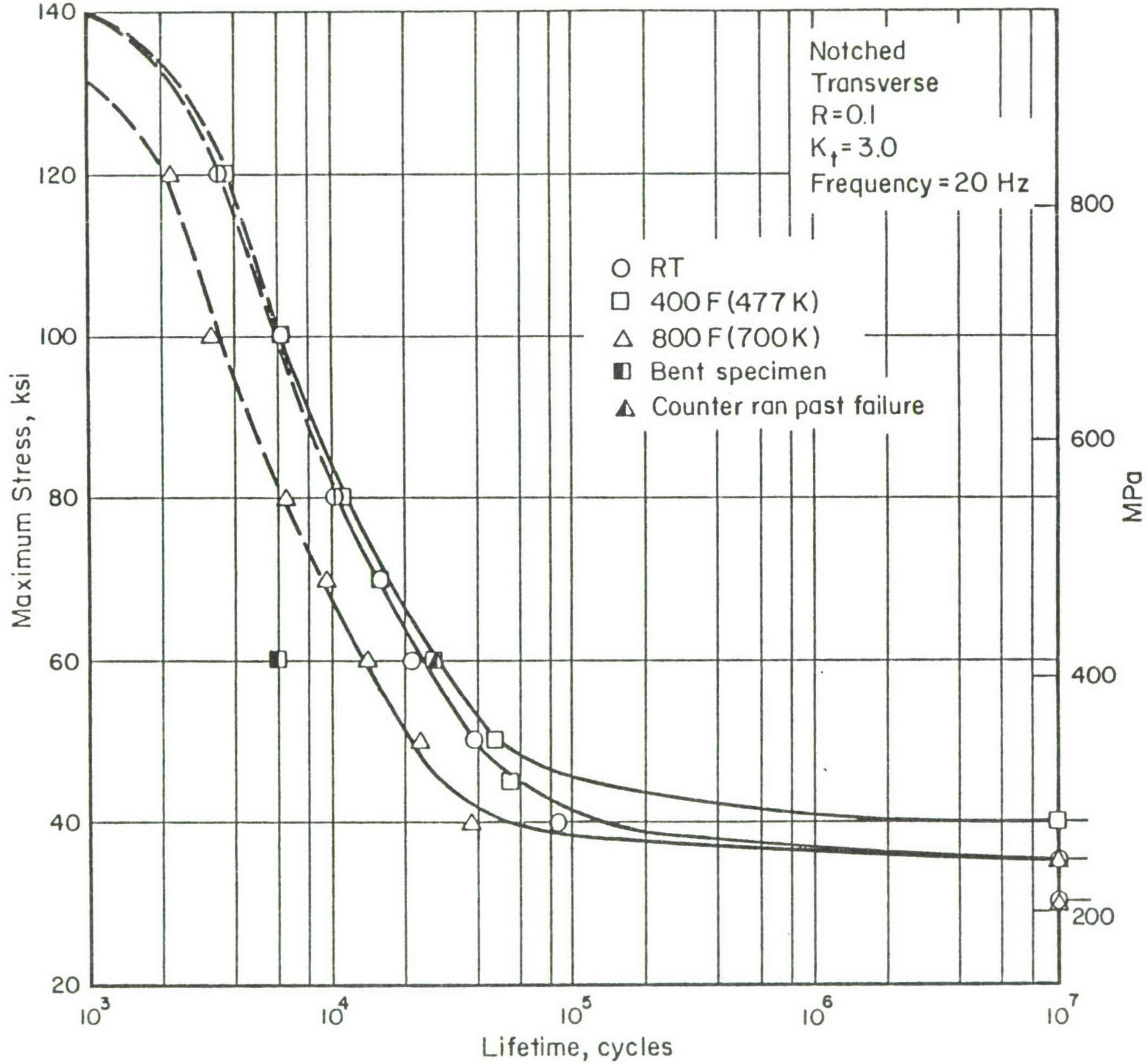

FIGURE 14. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) CUSTOM 450 STAINLESS STEEL STRIP

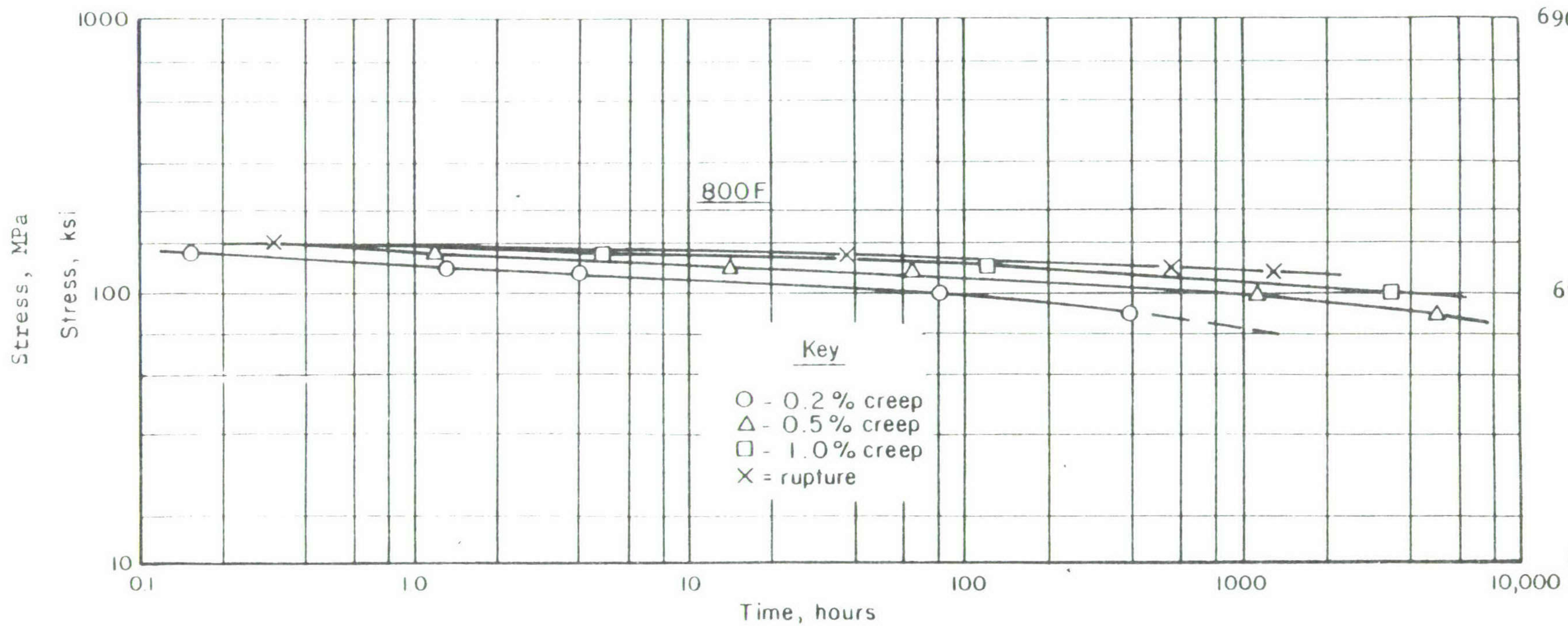

FIGURE 15. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR CUSTOM 450 STAINLESS STEEL STRIP (LONG TRANSVERSE)

Ti-15V-3Cr-3Al-3Sn Alloy

Material Description

This alloy is a recent development of Timet. The development aim was for a formable, heat-treatable, high-toughness sheet material as a possible higher-strength replacement for Ti-6Al-4V in various applications.

The Ti-15V-3Cr-3Al-3Sn sheet used in this evaluation was nominally 0.080-inch (2.032 mm) thick, from Timet heat number P2360. The alloy was supplied in the solution-annealed condition. The composition was as follows:

Chemical Composition	Percent
C	.015
Fe	.16
N	.014
Al	3.2
Cr	3.2
V	15.0
Sn	3.1
H	.017
O	.11

Processing and Heat Treating

Specimens were heat treated at 925 F (769 K) for 8 hours and air cooled. This heat treatment was selected, after discussions with Timet personnel, to achieve optimum fracture toughness for the alloy. Other treatments may be used to obtain different strength properties. Specimens were sectioned from the sheet as shown in Figure 16.

Test Results

Tension. Results of tensile tests at room temperature, 400 F (477 K), and 800 F (700 K) for longitudinal and transverse specimens are given in Table 9. Typical stress-strain curves at temperature are presented in Figures 17 and 18. Effect-of-temperature curves are shown in Figure 23.

Compression. Results of compression tests at room temperature, 400 F (477 K), and 800 F (700 K) for longitudinal and transverse specimens are given in Table 10. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 19 through 22. Effect-of-temperature curves are shown in Figure 24.

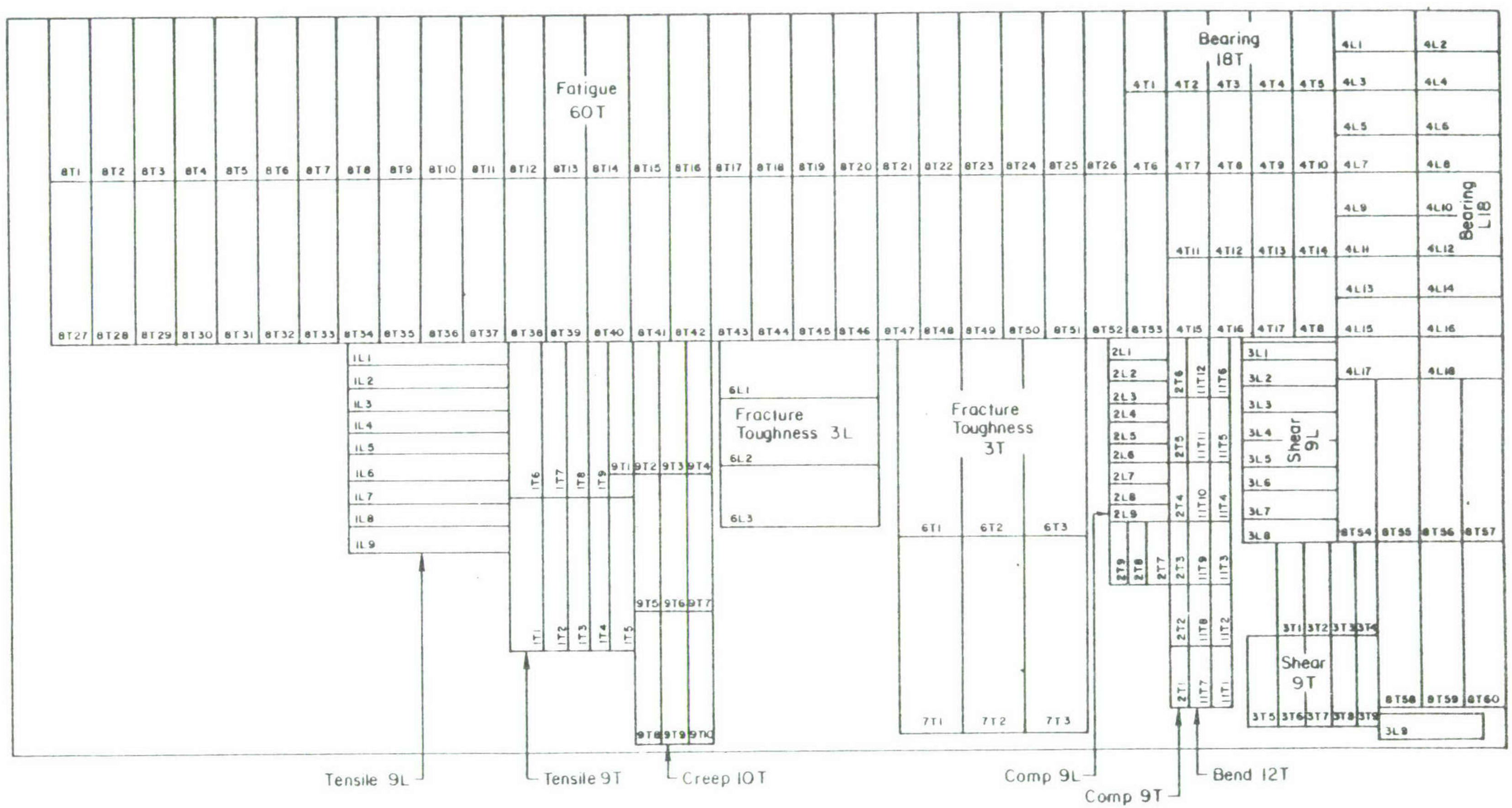

FIGURE 16. SPECIMEN LAYOUT FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET

Shear. Shear test results at room temperature, 400 F (477 K), and 800 F (700 K) for longitudinal and transverse specimens are shown in Table 11. Effect-of-temperature curves are presented in Figure 25.

Bearing. Results of bearing tests at e/D = 1.5 and e/D = 2.0 for longitudinal and transverse specimens at room temperature, 400 F (477 K), and 800 F (700 K) are given in Table 12. Effect-of-temperature curves are presented in Figure 26.

Fracture Toughness. Results of center notch sheet type specimen tests for longitudinal and transverse directions are presented in Table 13. Specimens were 0.08 inch (2.04 mm) thick x 3.00 inch (76.2 mm) wide x 9 inch (228.6 mm) span. The net section stress at fracture was less than the tensile yield strength so the data is valid in accordance with the Damage Tolerant Design Handbook section 11.1.2.

Crack Propagation. Results from 3 transverse specimens are shown in Figure 27. The tests were at room temperature.

Fatigue. Axial load fatigue tests results for transverse unnotched and notched specimens at room temperature, and 800 F (700 K) are given in Tables 14 and 15. S-N curves are presented in Figures 28 and 29.

Creep and Stress-Rupture. Tests were conducted at 800 F (700 K) on transverse specimens. Test results are given in Table 16. Log-stress versus log-time curves are presented in Figure 30.

Bend. Tests were conducted at room temperature on transverse specimens 3 inches (76.3 mm) long x 1 inch (25.4 mm) x 0.04 inch (1.02 mm). The minimum radius is 0.125 inch (3.12 mm).

Thermal Expansion. The coefficient of thermal expansion for this material is 5.5 in./in./F x 10^{-6} (RT to 800 F) [9.9 m/m K x 10^{-6} (RT to 700 K)].

Density. The density is 0.172 lb./in.^{3} (4.76 g/cm^3).

TABLE 9. TENSILE TEST RESULTS FOR SOLUTION TREATED AND AGED Ti-15V-3C-3Al-3Sn ALLOY SHEET

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 2 Inches (50.8 mm), percent	Tensile Modulus, 10^3 ksi	(GPa)
Longitudinal at Room Temperature							
1L-1	177.1	(1221.1)	160.9	(1109.4)	9.0	13.9	(95.8)
1L-2	179.2	(1235.6)	164.7	(1135.6)	8.5	14.8	(102.0)
1L-3	178.6	(1231.4)	164.6	(1134.9)	8.5	14.5	(100.0)
Average	178.3	(1229.4)	163.4	(1126.6)	8.7	14.4	(99.3)
Transverse at Room Temperature							
1T-1	182.3	(1257.0)	168.5	(1161.8)	8.0	14.3	(98.6)
1T-2	182.1	(1255.6)	168.1	(1159.0)	8.5	14.2	(97.9)
1T-3	177.3	(1222.5)	162.7	(1121.8)	8.0	14.5	(100.0)
Average	180.6	(1245.2)	166.4	(1147.3)	8.2	14.3	(98.6)
Longitudinal at 400 F (477 K)							
1L-4	163.7	(1128.7)	141.7	(977.0)	7.5	13.4	(92.4)
1L-5	164.3	(1132.8)	140.9	(971.5)	8.0	13.3	(91.7)
1L-6	165.0	(1137.7)	143.9	(992.2)	8.0	13.4	(92.4)
Average	164.3	(1132.8)	142.2	(980.5)	7.8	13.4	(92.4)
Transverse at 400 F (477 K)							
1T-4	166.6	(1148.7)	144.6	(997.0)	7.0	13.6	(93.8)
1T-5	165.5	(1141.1)	143.4	(988.7)	7.5	13.5	(93.1)
1T-6	166.9	(1150.8)	145.5	(1003.2)	7.5	13.6	(93.8)
Average	166.3	(1146.6)	144.5	(996.3)	7.3	13.6	(93.8)
Longitudinal at 800 F (700 K)							
1L-7	145.5	(1003.2)	123.2	(849.5)	12.5	11.9	(82.1)
1L-8	144.6	(997.0)	119.5	(824.0)	13.5	12.4	(85.5)
1L-9	144.7	(997.7)	121.6	(838.4)	13.0	12.5	(86.2)
Average	144.9	(999.1)	121.4	(837.1)	13.0	12.3	(84.8)
Transverse at 800 F (700 K)							
1T-7	146.4	(1009.4)	124.1	(855.7)	12.5	12.1	(83.4)
1T-8	146.8	(1012.2)	122.4	(843.9)	10.0	12.0	(82.7)
1T-9	146.4	(1009.4)	124.8	(860.5)	11.5	12.3	(84.8)
Average	146.5	(1010.1)	123.8	(853.6)	11.3	12.1	(83.4)

TABLE 10. COMPRESSION TEST RESULTS FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	(MPa)	Compression Modulus, 10^3 ksi	(GPa)
	Longitudinal at Room Temperature			
2L-1	172.1	(1186.6)	15.7	(108.3)
2L-2	168.2	(1159.7)	15.6	(107.6)
2L-3	173.7	(1197.7)	15.8	(108.9)
Average	171.3	(1181.3)	15.7	(108.3)
	Transverse at Room Temperature			
2T-1	173.3	(1194.9)	15.8	(108.9)
2T-2	179.8	(1239.7)	16.1	(111.0)
2T-3	182.6	(1259.0)	16.1	(111.0)
Average	178.6	(1231.2)	16.0	(110.3)
	Longitudinal at 400 F (477 K)			
2L-4	152.8	(1053.6)	15.2	(104.8)
2L-5	156.6	(1079.8)	15.1	(104.1)
2L-6	163.0	(1123.9)	15.5	(106.9)
Average	157.5	(1085.7)	15.3	(105.5)
	Transverse at 400 F (477 K)			
2T-4	161.4	(1112.9)	15.3	(105.5)
2T-5	160.3	(1105.3)	15.4	(106.2)
2T-6	155.8	(1074.2)	15.2	(104.8)
Average	159.2	(1097.5)	15.3	(105.5)
	Longitudinal at 800 F (700 K)			
2L-7	142.6	(983.2)	13.5	(93.1)
2L-8	145.1	(1000.5)	13.5	(93.1)
2L-9	139.0	(958.4)	13.1	(90.3)
Average	142.2	(980.7)	13.4	(92.2)
	Transverse at 800 F (700 K)			
2T-7	139.6	(962.5)	13.0	(89.6)
2T-8	146.0	(1006.7)	13.5	(93.1)
2T-9	130.6	(900.5)	13.5	(93.1)
Average	138.7	(956.6)	13.3	(91.9)

TABLE 11. **RESULTS OF SHEET SHEAR TESTS ON SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET**

Specimen Number		Ultimate Shear Strength, ksi	(MPa)
	Longitudinal at Room Temperature		
3L-1		114.4	(788.8)
3L-2		113.2	(780.5)
3L-3		113.6	(783.3)
	Average	113.7	(784.2)
	Transverse at Room Temperature		
3T-1		114.6	(790.2)
3T-2		116.6	(804.0)
3T-3		116.4	(802.6)
	Average	115.9	(798.9)
	Longitudinal at 400 F (477 K)		
3L-4		101.5	(699.8)
3L-5		102.4	(706.0)
3L-6		105.3	(726.0)
	Average	103.1	(710.6)
	Transverse at 400 F (477 K)		
3T-4		101.8	(701.9)
3T-5		102.5	(706.7)
3T-6		102.5	(706.7)
	Average	102.3	(705.1)
	Longitudinal at 800 F (700 K)		
3L-7		91.1	(628.1)
3L-8		92.8	(629.9)
3L-9		92.9	(640.5)
	Average	92.3	(636.2)
	Transverse at 800 F (700 K)		
3T-7		91.7	(632.3)
3T-8		92.9	(640.5)
3T-9		92.5	(637.8)
	Average	92.4	(636.9)

TABLE 12. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR SOLUTION TREATED AND AGED Ti-15V-3C-3Al-3Sn ALLOY SHEET

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Bearing Yield Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
	Longitudinal at Room Temperature			
4L-1	292.1 (2014.0)	323.4 (2229.8)	252.4 (1740.3)	268.6 (1852.0)
4L-2	284.2 (1959.6)	314.2 (2166.4)	253.3 (1746.5)	270.1 (1862.3)
4L-3	288.2 (1987.1)	333.3 (2248.1)	229.1 (1579.6)	257.4 (1774.8)
Average	288.2 (1987.1)	323.6 (2231.2)	244.9 (1688.6)	265.4 (1829.9)
	Transverse at Room Temperature			
4T-1	266.2 (1835.4)	333.0 (2296.0)	255.9 (1764.4)	283.2 (1952.7)
4T-2	275.6 (1900.3)	334.6 (2307.1)	250.1 (1724.4)	291.8 (2012.0)
4T-3	275.2 (1897.5)	343.2 (2366.4)	252.3 (1739.6)	290.5 (2003.0)
Average	272.3 (1877.5)	336.9 (2322.9)	252.8 (1743.1)	288.5 (1989.2)
	Longitudinal at 400 F (477 K)			
4L-4	242.9 (1674.8)	295.9 (2040.2)	223.6 (1541.7)	259.1 (1786.5)
4L-5	245.2 (1690.7)	306.8 (2115.4)	225.4 (1554.1)	256.5 (1768.6)
4L-6	253.7 (1749.3)	242.4 (2016.1)	223.4 (1540.3)	251.3 (1732.7)
Average	247.3 (1705.1)	298.4 (2057.5)	224.1 (1545.2)	255.6 (1762.4)
	Transverse at 400 F (477 K)			
4T-4	253.6 (1748.6)	296.1 (2041.6)	225.4 (1554.1)	260.0 (1792.7)
4T-5	252.5 (1741.0)	298.0 (2054.7)	225.5 (1554.8)	260.4 (1795.5)
4T-6	253.6 (1748.6)	303.3 (2091.3)	226.8 (1563.8)	260.6 (1796.8)
Average	253.2 (1745.8)	299.1 (2062.3)	225.9 (1557.6)	260.3 (1794.8)
	Longitudinal at 800 F (700 K)			
4L-7	241.4 (1664.5)	288.3 (1987.8)	214.4 (1478.3)	234.3 (1615.5)
4L-8	243.1 (1676.2)	291.2 (2007.8)	209.0 (1441.1)	234.3 (1615.5)
4L-9	240.7 (1699.6)	293.1 (2020.9)	212.0 (1461.7)	234.0 (1613.4)
Average	241.7 (1666.5)	290.9 (2005.8)	211.8 (1460.4)	234.2 (1614.8)
	Transverse at 800 F (700 K)			
4T-7	239.5 (1651.4)	295.8 (2039.5)	203.9 (1405.9)	240.7 (1659.6)
4T-8	239.5 (1651.4)	300.1 (2069.2)	210.0 (1448.0)	237.2 (1635.5)
4T-9	239.5 (1651.4)	295.5 (2037.5)	208.7 (1439.0)	237.5 (1637.6)
Average	239.5 (1651.4)	297.1 (2048.5)	207.5 (1430.7)	238.5 (1644.5)

TABLE 13. FRACTURE TOUGHNESS TEST RESULTS FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET AT ROOM TEMPERATURE

Specimen Number	Thickness, B, inch	(mm)	Width, w, inches	(mm)	Maximum Stress, ksi	(MPa)	Initial Precrack, inches	(mm)	Apparent SIF, K_c, ksi$\sqrt{in.}$	$(MPa \cdot m^{\frac{1}{2}})$	Net Section Stress, ksi	(MPa)
6L-1	.0770	(1.956)	3.010	(20.75)	66.9	(461.3)	.4802	(12.19)	87.7	(96.5)	79.6	(548.8)
6L-3	.0775	(1.968)	3.010	(20.75)	70.7	(487.5)	.4832	(12.27)	93.1	(102.4)	84.2	(580.6)
Average					68.8	(474.4)			90.4	(99.4)	81.9	(564.7)
6T-1	.0762	(1.935)	3.008	(20.74)	68.0	(468.9)	.4850	(12.32)	89.8	(98.8)	81.1	(559.2)
6T-2	.0770	(1.956)	3.012	(20.77)	66.8	(460.6)	.4880	(12.39)	88.5	(97.4)	79.8	(550.2)
6T-3	.0770	(1.956)	3.012	(20.77)	70.7	(487.5)	.4934	(12.53)	94.3	(103.7)	84.6	(583.3)
Average					68.5	(472.3)			90.9	(100.0)	81.8	(564.2)

TABLE 14. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED SOLUTION TREATED AND AGED Ti-15V-3C-3Al-3Sn ALLOY SHEET AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)	Cycles to Failure
	Room Temperature	
8T-1	150.0 (1034.3)	3,620
8T-2	130.0 (896.4)	4,960
8T-3	110.0 (758.5)	7,610
8T-7	100.0 (689.5)	13,010
8T-4	90.0 (620.6)	25,570
8T-5	80.0 (551.6)	30,670
8T-6	70.0 (482.7)	38,230
8T-10	65.0 (448.2)	73,060
8T-8	60.0 (413.7)	4,237,000
8T-12	55.0 (379.2)	10,380,000 (a)
	800 F (700 K)	
8T-11	120.0 (827.4)	5,700
8T-16	110.0 (758.5)	4,900
8T-13	100.0 (689.5)	6,200
8T-14	90.0 (620.6)	8,100
8T-15	80.0 (551.6)	15,000
8T-18	75.0 (517.1)	19,000
8T-17	70.0 (482.7)	2,394,300
8T-19	65.0 (448.2)	10,000,000 (a)

(a) Did not fail.

TABLE 15. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-15V-Cr-3Al-3Sn ALLOY SHEET AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8T-31	80.0	(551.6)	2,600
8T-37	70.0	(482.7)	3,600
8T-32	60.0	(413.7)	5,800
8T-38	50.0	(344.8)	7,300
8T-33	40.0	(275.8)	16,200
8T-34	30.0	(206.9)	43,900
8T-35	25.0	(172.4)	66,900
8T-36	20.0	(137.9)	498,600
8T-39	17.5	(120.7)	10,000,000[a]
	800 F (700 K)		
8T-42	80.0	(551.6)	2,600
8T-44	70.0	(482.7)	3,600
8T-41	60.0	(413.7)	4,700
8T-47	50.0	(344.8)	7,600
8T-40	40.0	(275.8)	14,400
8T-45	35.0	(241.3)	17,400
8T-46	30.0	(206.9)	36,700
8T-43	30.0	(206.9)	1,794,300
8T-48	25.0	(172.4)	10,000,000[a]

(a) Did not fail.

TABLE 16. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET

Specimen Number	Stress, ksi (MPa)	Temperature, F (K)	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches (50.8 mm), percent	Minimum Creep Rate, percent/hour
			0.1	0.2	0.5	1.0	2.0				
9-1	143 (986)	800 (700)	--	--	--	--	--	--	0.1	10.9	--
9-2	120 (827)	800 (700)	0.03	0.10	0.35	0.8	2.4	1.247	21.9	20.0	0.59
9-3	105 (724)	800 (700)	0.10	0.25	1.0	2.5	7.0	0.878	101.8	25.2	0.14
9-4	70 (483)	800 (700)	0.20	0.9	5.6	19.4	75	0.456	2314.4	31.3	0.0058
9-5	30 (207)	800 (700)	4.2	13.5	87	400[b]	--	0.219	144.8[a]	0.833	0.0015
9-6	20 (138)	800 (700)	36	117	520[b]	--	--	0.132	167.9[a]	0.363	0.00077
9-7	15 (103)	800 (700)	170	535	2500[b]	--	--	0.117	1075.5[a]	0.402	0.00016

(a) Test discontinued.

(b) Estimated.

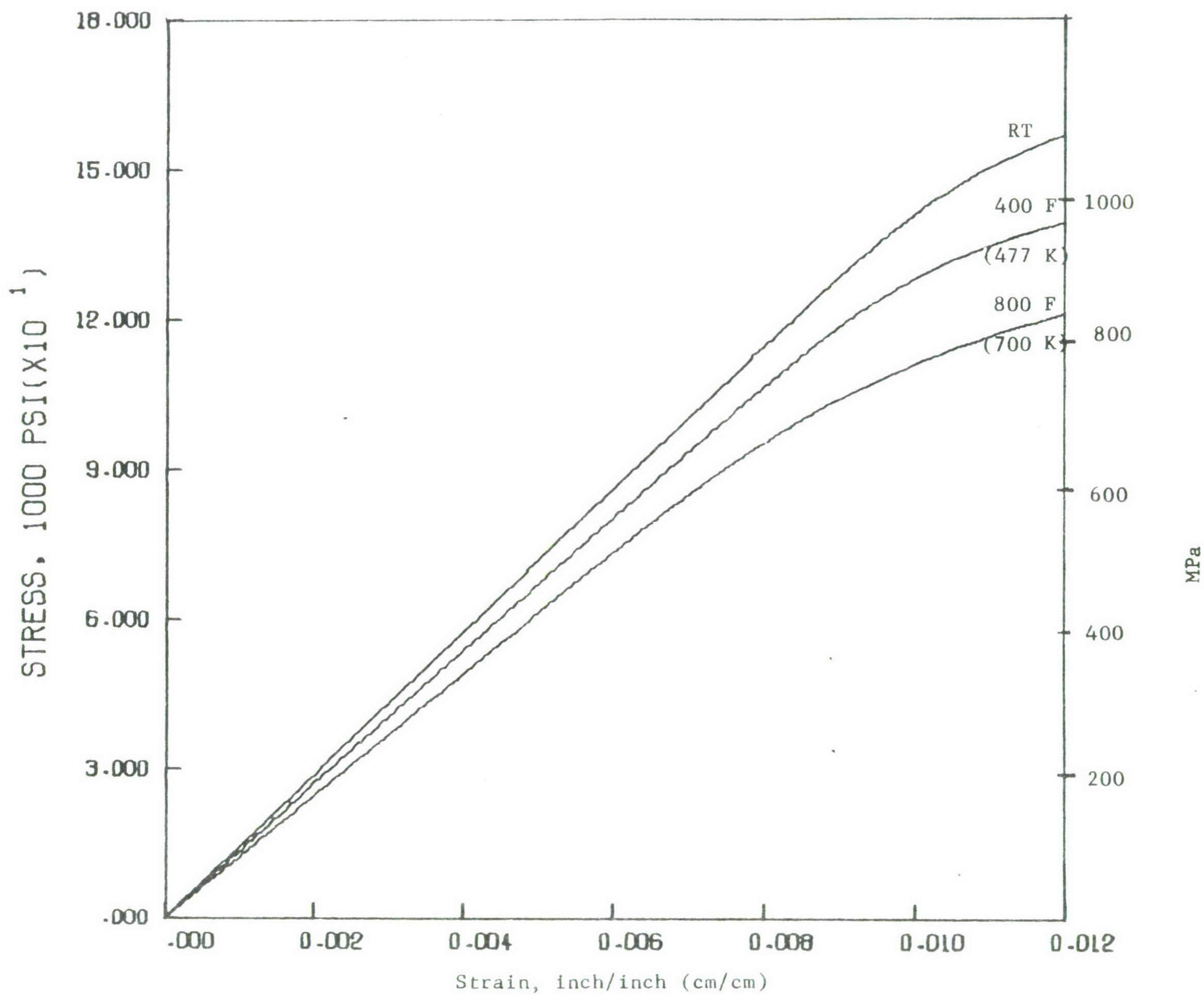

FIGURE 17. TYPICAL TENSILE STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET AT TEMPERATURE. (LONGITUDINAL)

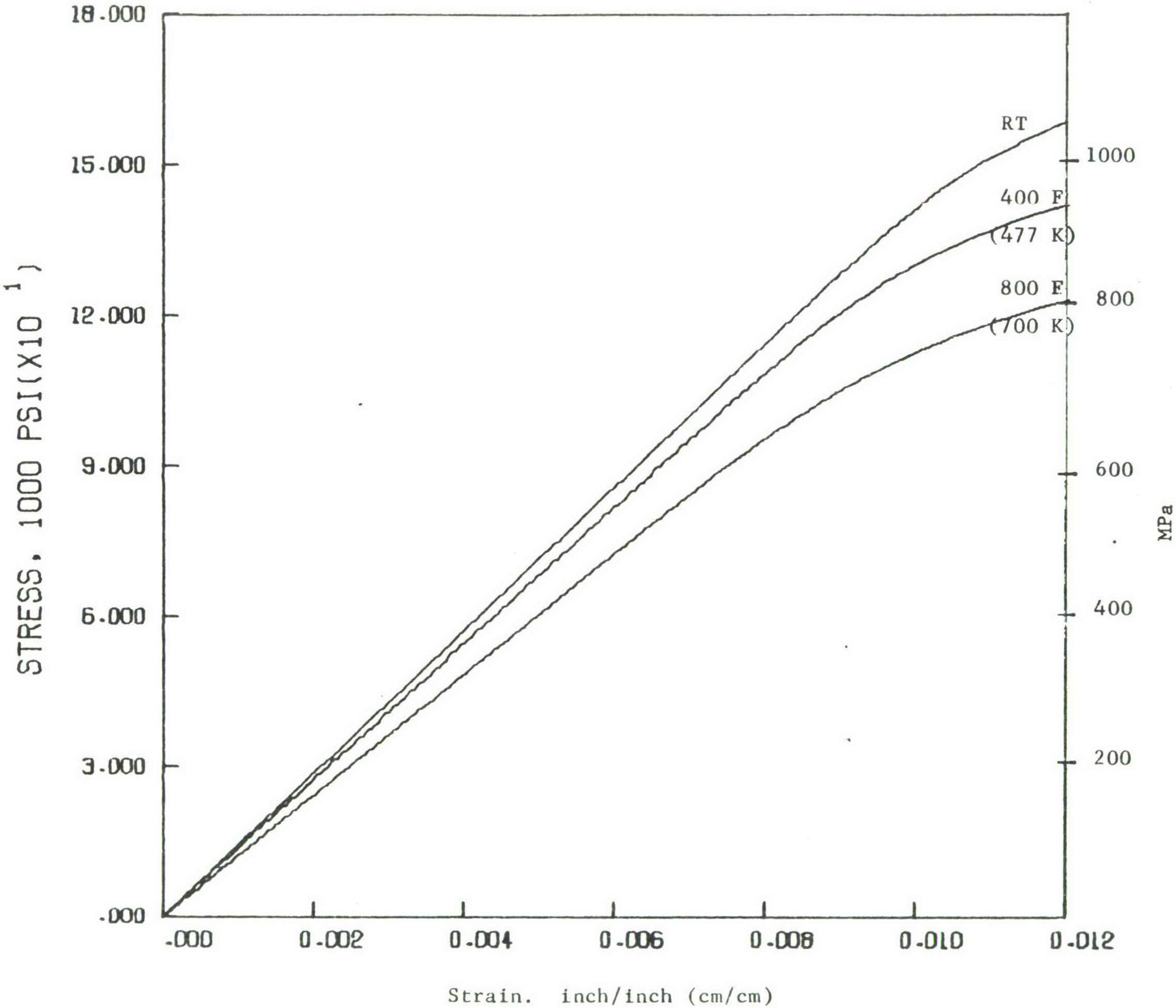

FIGURE 18. TYPICAL TENSILE STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET AT TEMPERATURE. (TRANSVERSE)

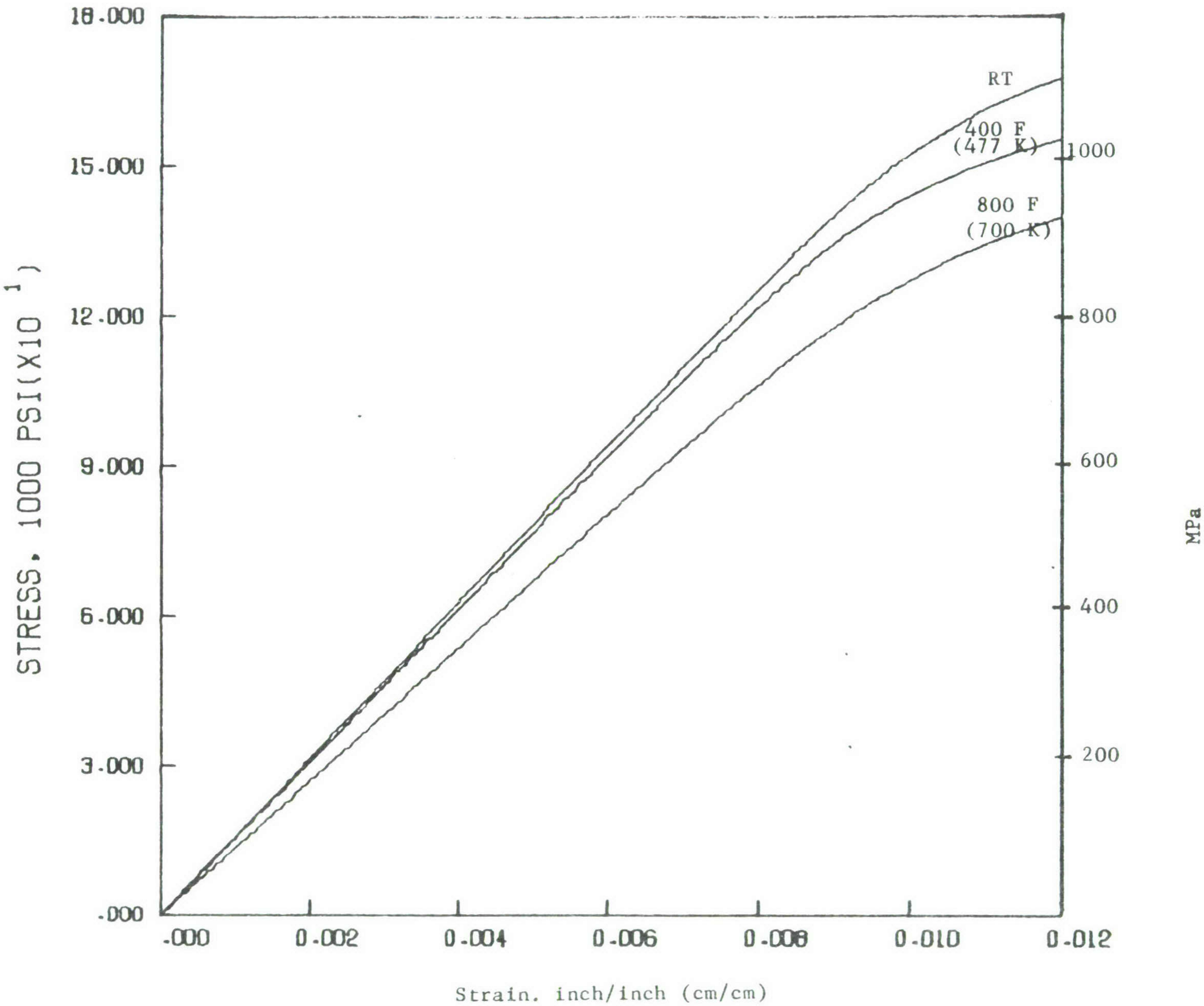

FIGURE 19. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY AT TEMPERATURE. (LONGITUDINAL)

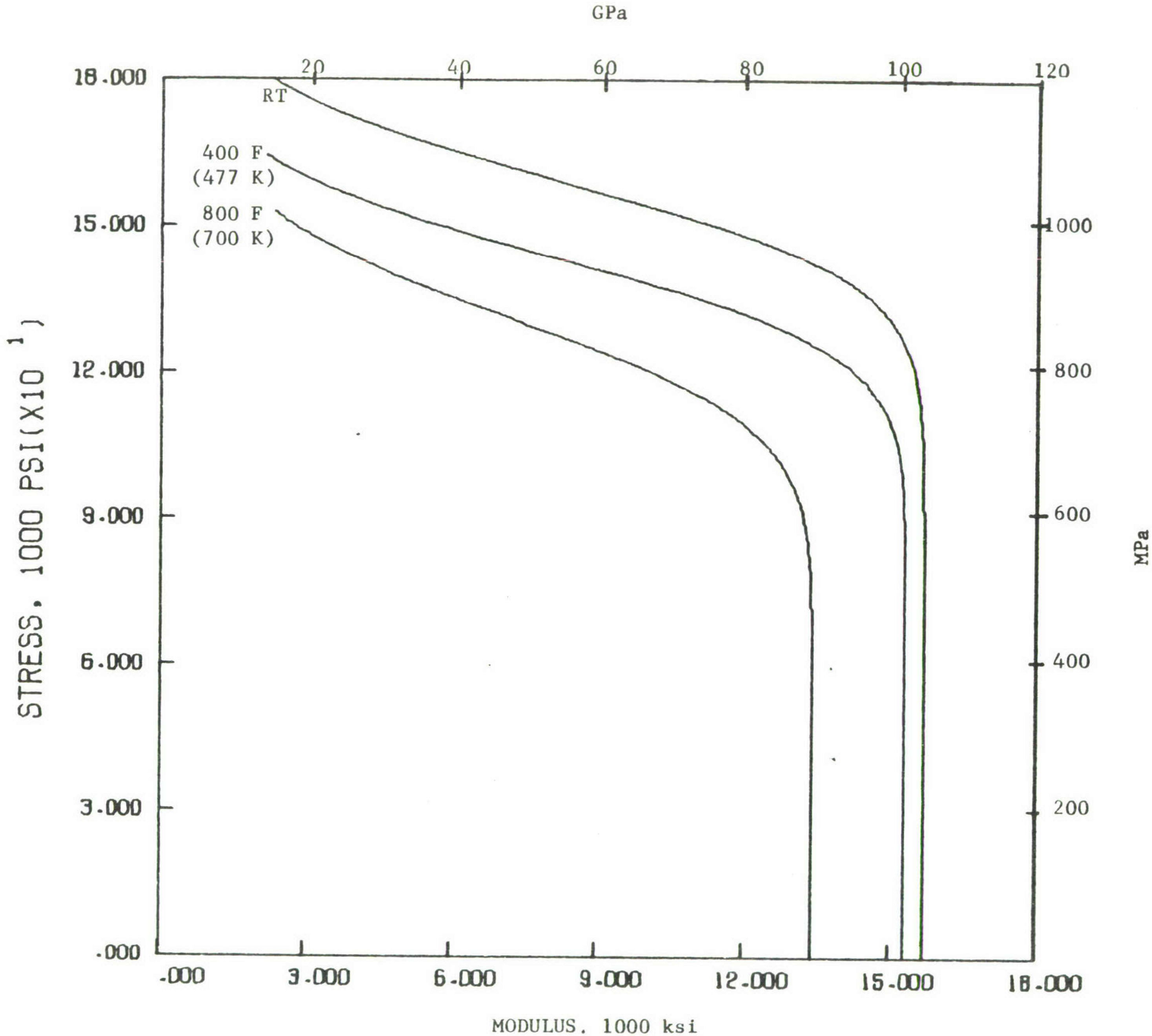

FIGURE 20. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET AT TEMPERATURE. (LONGITUDINAL)

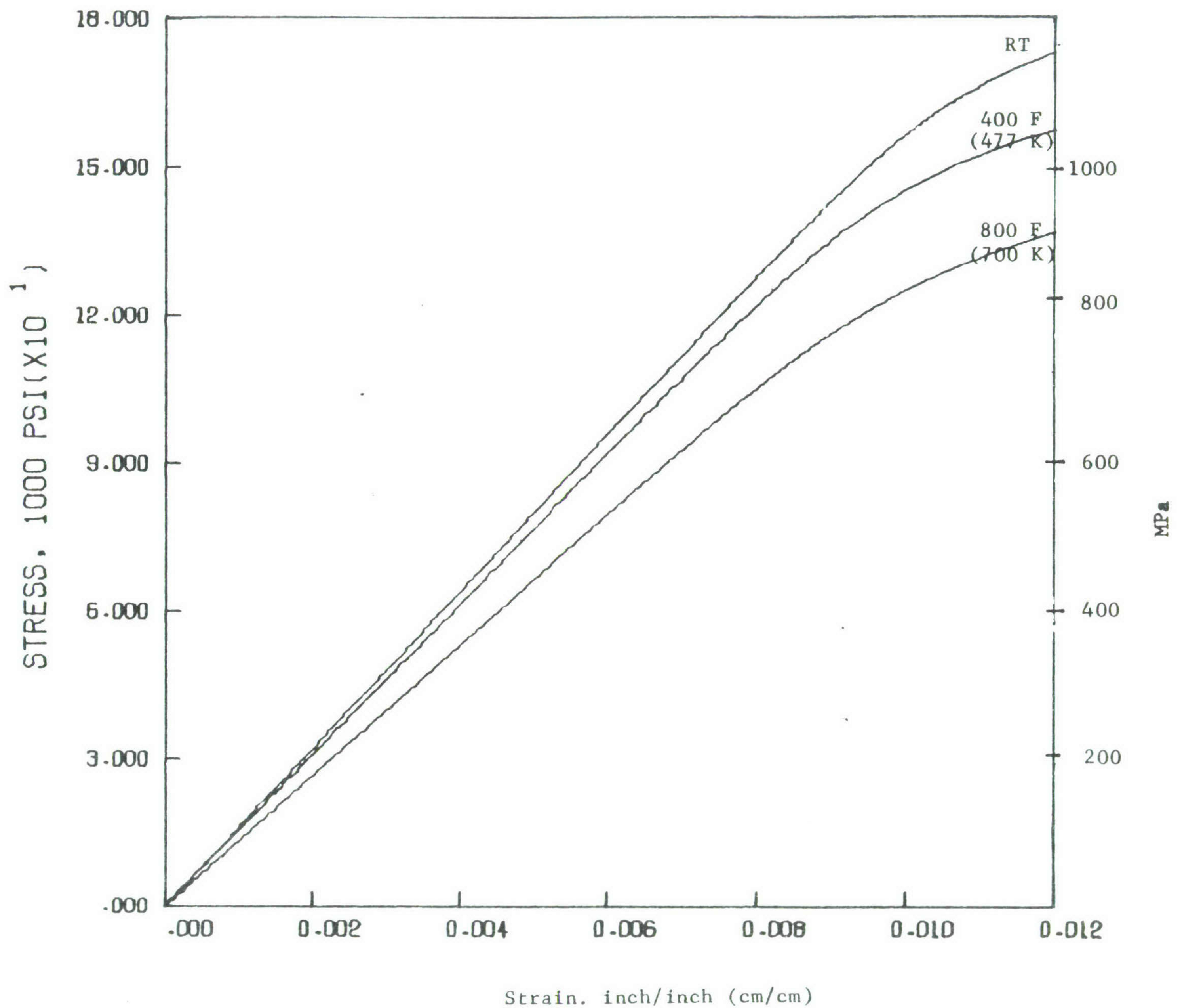

FIGURE 21. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET. (TRANSVERSE).

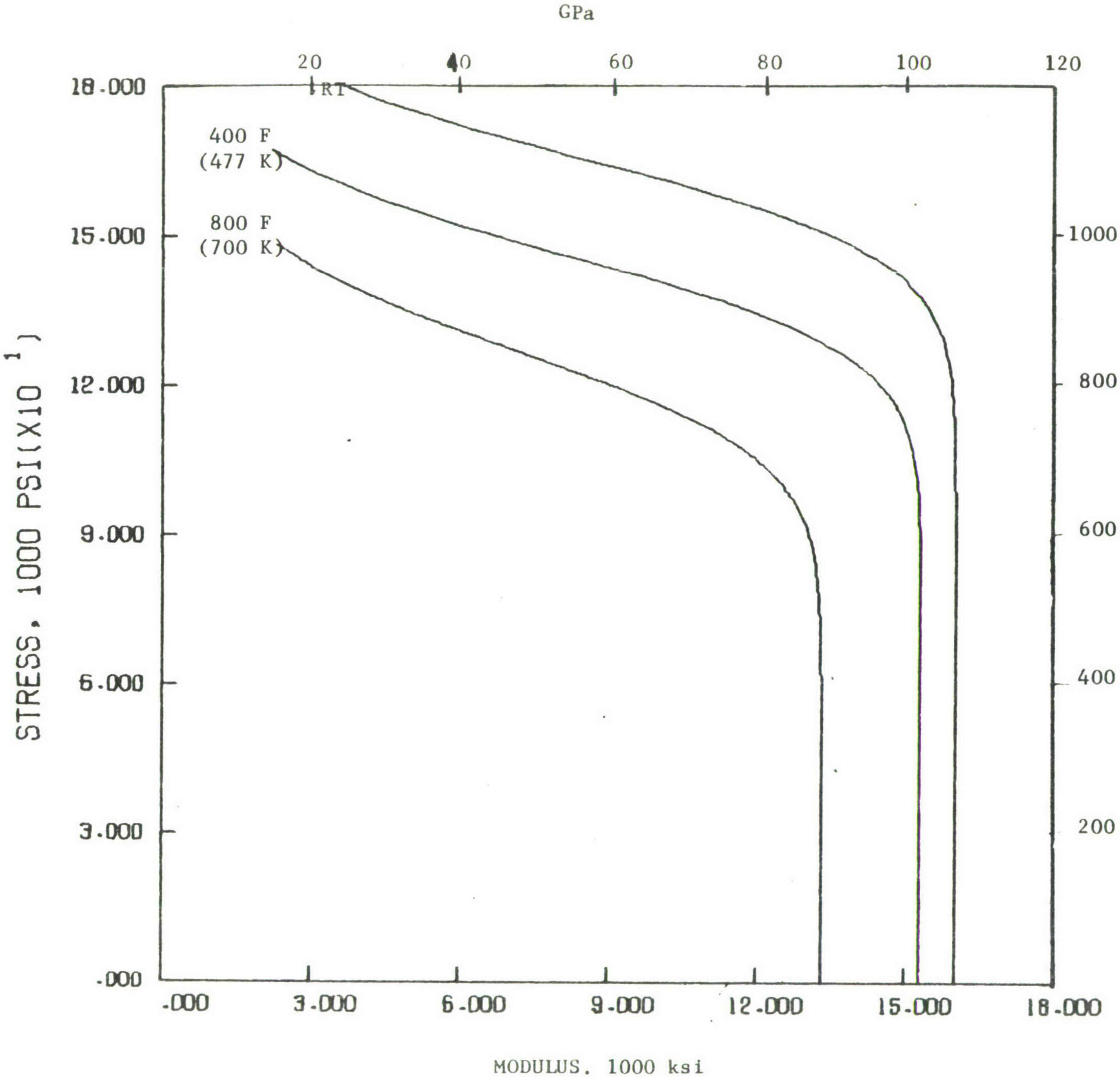

FIGURE 22. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET. (TRANSVERSE)

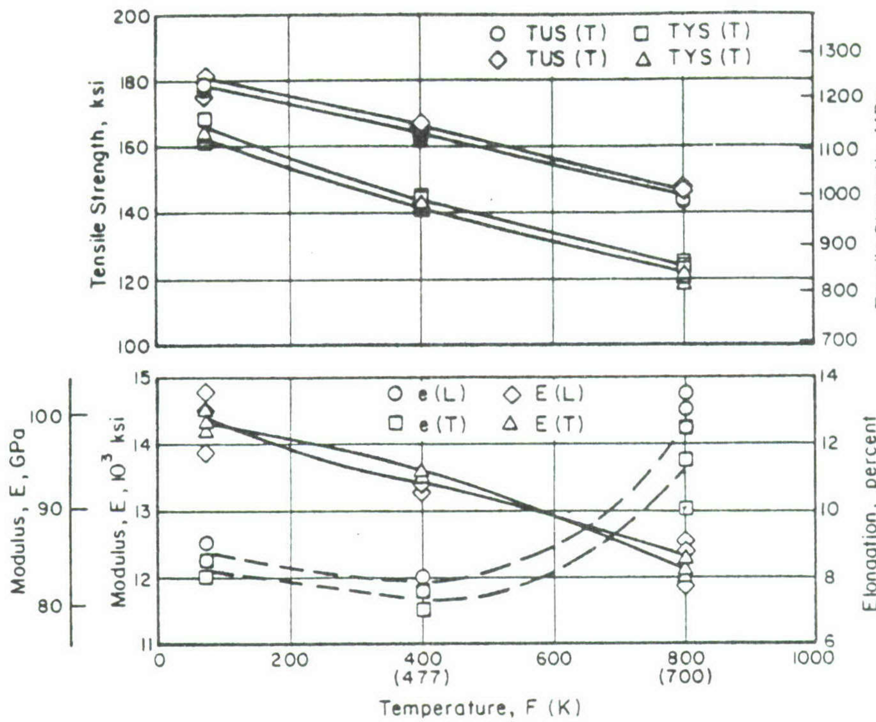

FIGURE 23. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

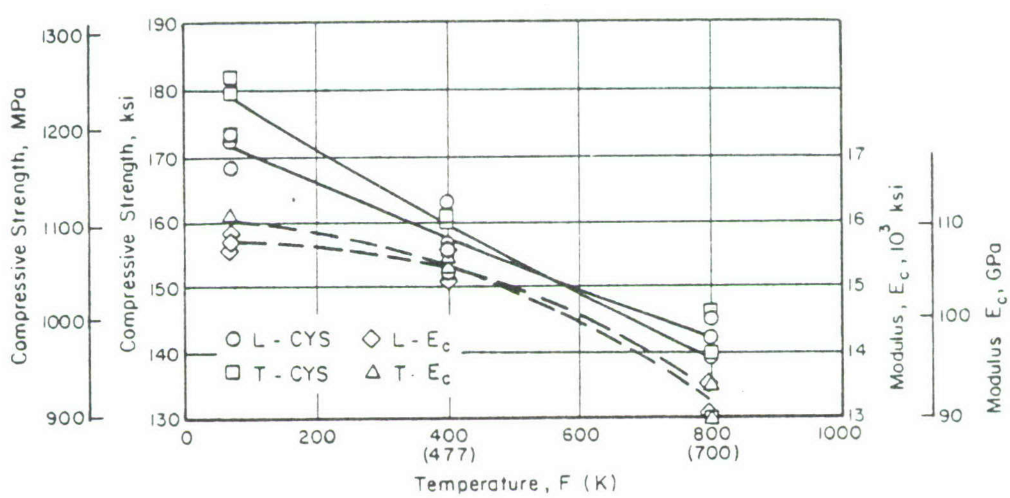

FIGURE 24. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

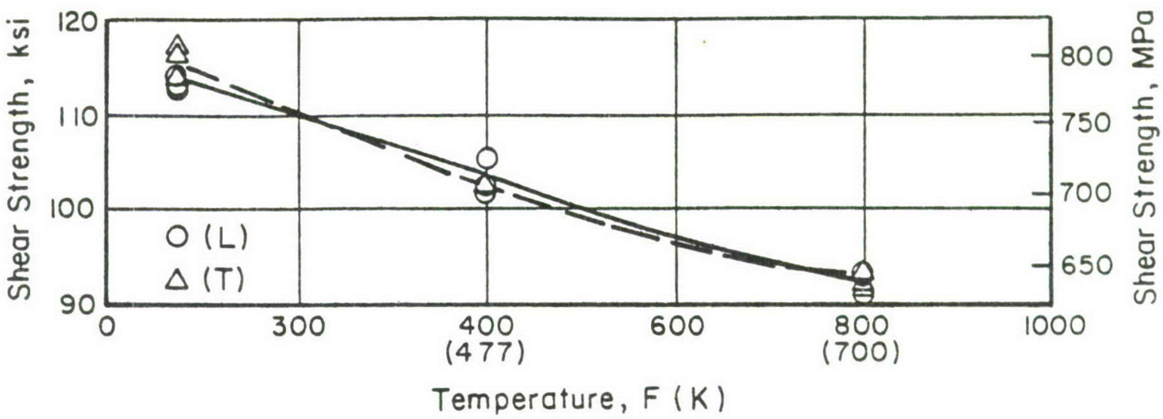

FIGURE 25. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

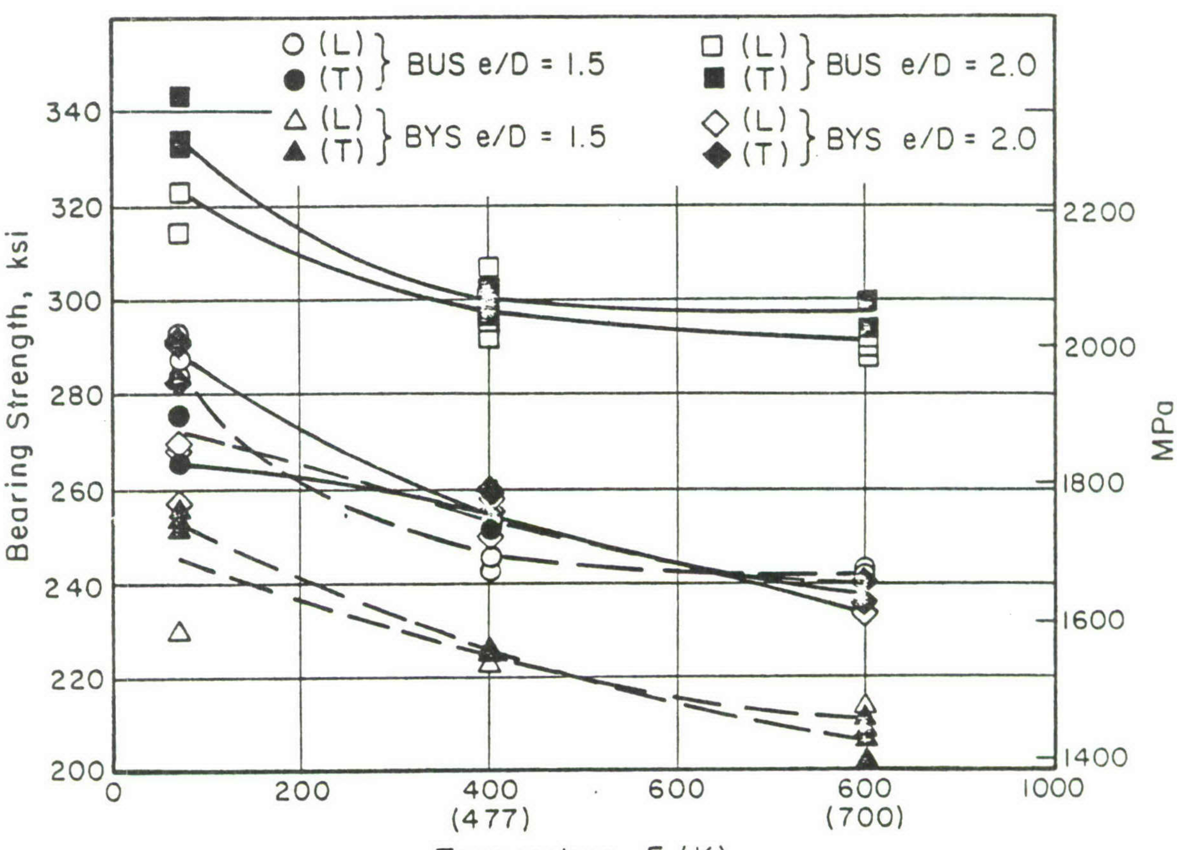

FIGURE 26. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

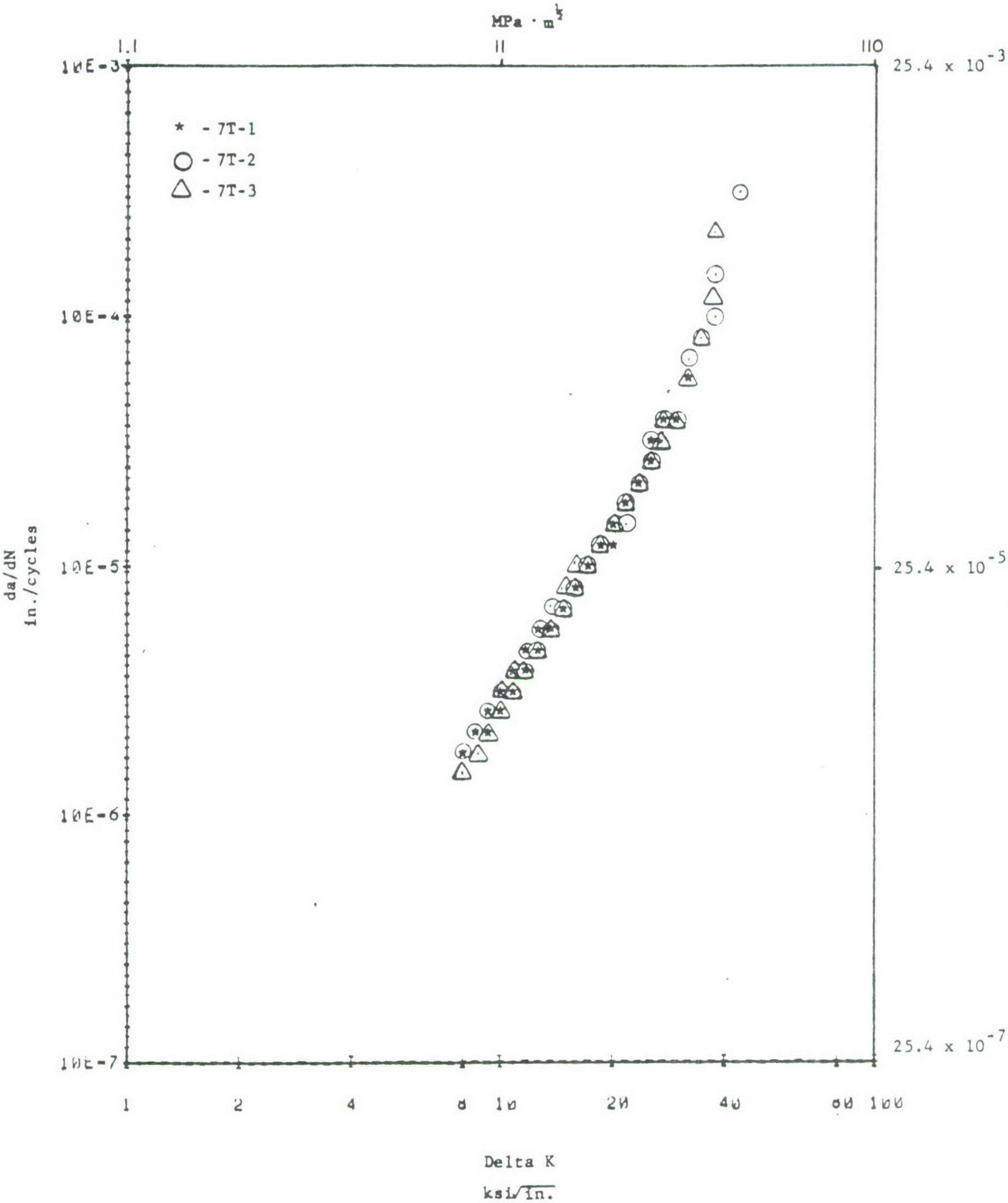

FIGURE 27. da/dN VERSUS DELTA K FOR SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

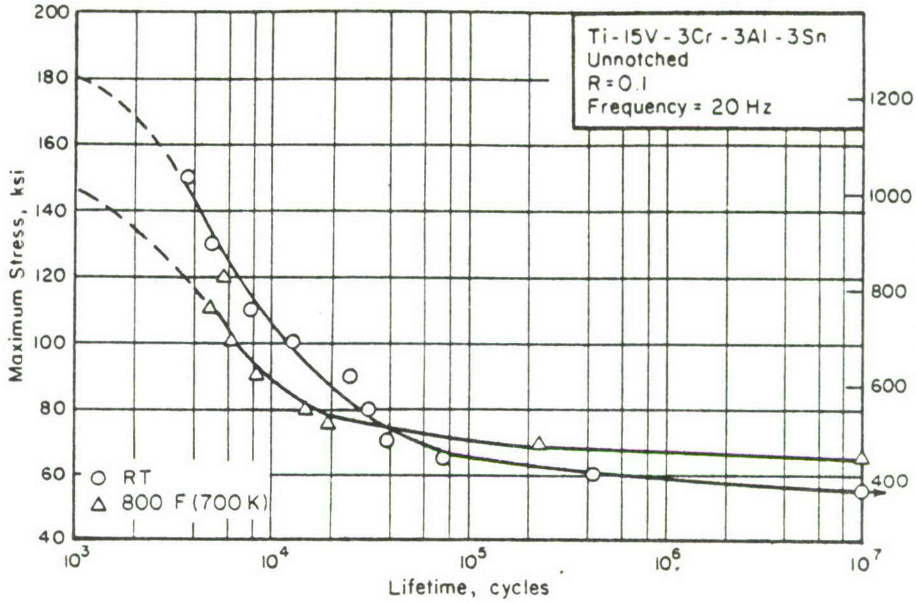

FIGURE 28. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

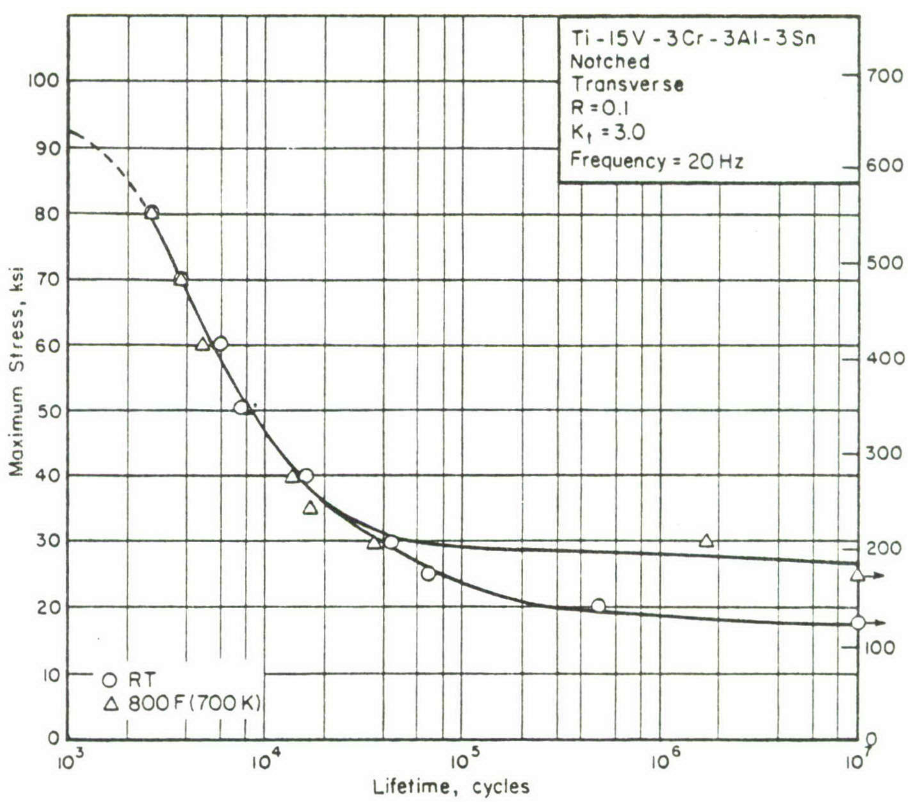

FIGURE 29. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) SOLUTION TREATED AND AGED Ti-15V-3Cr-3Al-3Sn SHEET

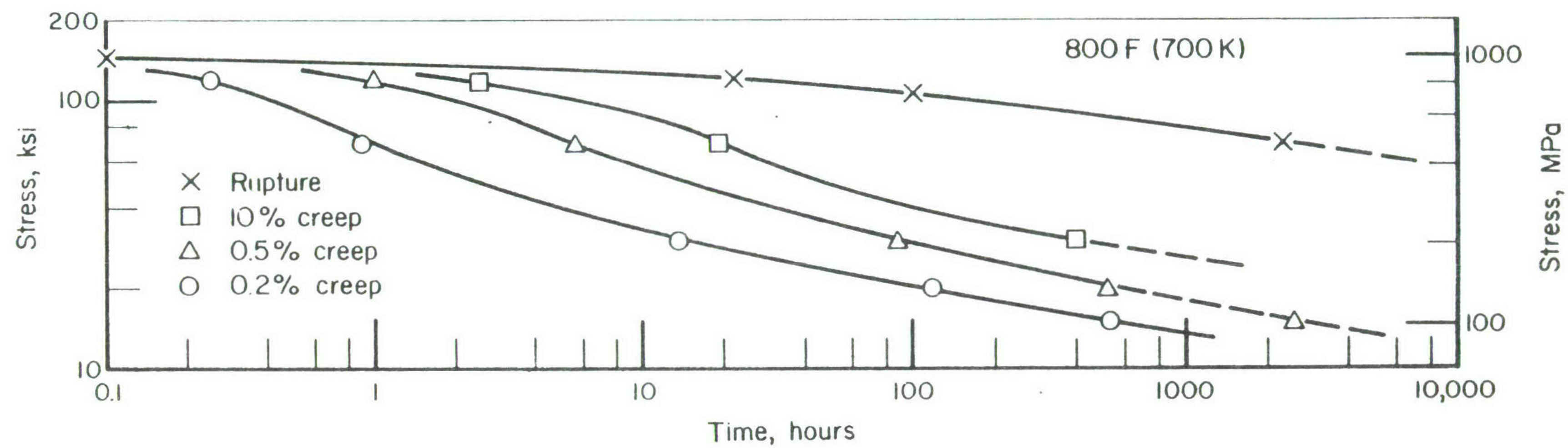

FIGURE 30. CREEP-RUPTURE DATA FOR SOLUTION-TREATED AND AGED Ti-15V-3Cr-3Al-3Sn ALLOY SHEET

A206-T7 Aluminum Castings

Material Description

A206 is a high-strength, aluminum casting alloy. The purpose of the alloy development was to preserve as much of the ductility and mechanical property gain of the previous development in Alloy 201 while reducing alloy costs to a level comparable to other premium casting alloys (e.g., A356-A357, etc.).

The material used in this evaluation was permanent mold, cast rectangular shapes of various thicknesses and sizes. The material was obtained through Trialco, Inc., and had the following composition:

Chemical Composition	Percent
Si	.02
Fe	.07
Cu	4.9
Mn	.24
Mg	.22
Ti	.14

Processing and Heat Treating

The alloy was evaluated in the as-received -T7 condition. Specimens were machined from casting blanks as follows:

Tensile, Compression, Shear, and Fatigue Specimens	3/4 x 3/4 x 7" blanks
Fracture Toughness Specimens	1 3/8 x 3 x 3" blanks
Bearing Specimens	≈ 1/4 x 3 x 4" blade castings.

Test Results

Tension. Results of tensile tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 17. Typical stress-strain curves at temperature are presented in Figure 31. Effect-of-temperature curves are presented in Figure 34.

Compression. Results of compression tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 18. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 32 and 33. Effect-of-temperature curves are presented in Figure 35.

Shear. Pin shear test results at room temperature, 250 F (394 K), and 350 F (450 K) are presented in Table 19. Effect-of-temperature curve is shown in Figure 36.

Bearing. Results of bearing tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 20. Effect-of-temperature curves are shown in Figure 37.

Fracture Toughness. Results from compact tension-type fracture toughness specimens are presented in Table 21.

Fatigue. Results of axial load fatigue tests at room temperature and 350 F (450 K) are given in Table 22 for unnotched specimens and Table 23 for notched specimens. S-N curves are presented in Figures 38 and 39.

Thermal Expansion. The coefficient of thermal expansion for this material is 10.7 in/in/F x 10^{-6} (RT to 212 F) [19.3 m/(m·k) x 10^{-6} (RT to 373 K)].

Density. The density is 0.101 lb./in^3 (2.80 g/cm^3).

TABLE 17. RESULTS OF TENSILE TESTS FOR A206-T7 ALUMINUM CASTING

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 2 Inches (50.8 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi	(GPa)
				Room Temperature				
1-1	62.5	(430.9)	49.7	(342.7)	12.0	18.0	10.2	(70.3)
1-2	63.8	(439.9)	50.8	(350.3)	12.0	31.7	10.3	(71.0)
1-3	63.2	(435.8)	50.5	(348.2)	11.0	28.2	10.1	(69.6)
Average	63.2	(435.8)	50.3	(346.8)	11.7	26.0	10.2	(70.3)
				250 F (394 K)				
1-4	55.9	(385.4)	46.2	(318.5)	15.0	46.6	10.2	(70.3)
1-5	55.7	(384.1)	46.0	(317.2)	19.0	56.3	9.6	(66.2)
1-6	55.4	(382.0)	45.6	(314.4)	8.0	18.4	10.2	(70.3)
Average	55.7	(384.1)	45.9	(316.5)	14.0	40.4	10.0	(69.0)
				350 F (450 K)				
1-7	47.5	(327.5)	43.2	(297.9)	16.0	47.4	9.3	(64.1)
1-8	49.4	(340.6)	44.3	(305.4)	20.0	55.6	9.1	(62.7)
1-9	47.9	(330.3)	43.8	(302.0)	17.0	55.1	9.8	(67.6)
Average	48.3	(333.0)	43.8	(302.0)	17.7	53.7	9.4	(64.8)

TABLE 18. RESULTS OF COMPRESSION TESTS FOR A206-T7 ALUMINUM CASTING

Specimen Number		0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(GPa)
		Room Temperature			
2-1		53.8	(371.0)	10.2	(70.3)
2-2		55.5	(382.7)	10.2	(70.3)
2-3		52.5	(362.0)	10.2	(70.3)
	Average	53.9	(371.6)	10.2	(70.3)
		250 F (394 K)			
2-4		50.6	(348.9)	9.4	(64.8)
2-5		50.3	(346.8)	9.7	(66.9)
2-6		50.1	(345.4)	9.6	(66.2)
	Average	50.3	(346.8)	9.6	(66.2)
		350 F (450 K)			
2-7		46.4	(319.9)	8.8	(60.7)
2-8		45.9	(316.5)	8.7	(60.0)
2-9		46.2	(318.5)	9.3	(64.1)
	Average	46.2	(318.5)	8.9	(61.4)

TABLE 19. PIN SHEAR TEST RESULTS FOR A206-T7 ALUMINUM CASTING

Specimen Number		Ultimate Shear Strength, ksi	(MPa)
	Room Temperature		
3-1		36.92	(254.6)
3-2		36.77	(253.5)
3-3		38.20	(263.4)
	Average	37.30	(257.2)
	250 F (394 K)		
3-4		34.26	(236.2)
3-5		33.80	(233.1)
3-6		33.00	(227.5)
	Average	33.69	(232.3)
	350 F (450 K)		
3-7		26.33[a]	(181.5)
3-8		30.37	(209.4)
3-9		29.90	(206.2)
	Average	30.14	(207.8)

(a) Overheated; not used in average.

TABLE 20. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR A206-T7 ALUMINUM CASTING

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Bearing Yield Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
		Room Temperature		
4-1	99.7 (687.6)	132.6 (914.3)	77.6 (535.1)	94.5 (651.6)
4-2	100.2 (690.9)	131.6 (907.4)	80.4 (554.4)	96.0 (661.9)
4-3	101.4 (699.2)	130.0 (896.4)	78.8 (543.3)	95.9 (661.2)
Average	100.4 (692.5)	131.4 (906.0)	78.9 (544.2)	95.5 (658.2)
		250 F (394 K)		
4-4	91.4 (630.2)	113.0 (779.1)	73.1 (504.0)	89.6 (617.8)
4-5	91.9 (633.7)	113.9 (785.3)	73.4 (506.1)	91.1 (628.1)
4-6	91.9 (633.7)	114.0 (786.0)	73.9 (509.5)	92.5 (637.8)
Average	91.9 (632.5)	113.6 (783.5)	73.5 (506.6)	91.1 (627.9)
		350 F (450 K)		
4-7	80.6 (555.7)	91.9 (633.7)	70.0 (482.7)	81.5 (561.9)
4-8	80.0 (551.6)	92.2 (635.7)	69.2 (477.1)	82.7 (570.2)
4-9	76.6 (528.2)	--[a]	68.4 (471.6)	--[a]
Average	79.1 (545.2)	92.1 (634.7)	69.2 (477.1)	82.1 (566.1)

(a) Machine malfunction.

TABLE 21. FRACTURE TOUGHNESS TEST RESULTS FOR COMPACT TENSION TYPE SPECIMENS OF A206-T7 ALUMINUM CASTING

Specimen Number	Width, W, inches	(mm)	Thickness, B, inches	(mm)	a, inches	(mm)	P_Q, lbs.	(kg)	P_{max}, lbs.	(kg)	$f(\frac{a}{W})$	K_Q[(a)], $ksi \cdot in.^{\frac{1}{2}}$	$(MPa \cdot m^{\frac{1}{2}})$	R_{sc}
6-1	2.370	(60.20)	1.250	(31.75)	1.000	(25.40)	9,350	(4,241)	10,900	(4,944)	7.65	37.2	(40.92)	1.06
6-2	2.370	(60.20)	1.250	(31.75)	1.010	(25.65)	9,860	(4,472)	11,500	(5,216)	7.79	39.9	(43.89)	1.14
6-3	2.370	(60.20)	1.250	(31.75)	1.000	(25.40)	9,600	(4,354)	10,800	(4,899)	7.65	38.2	(42.02)	1.04
6-4	2.370	(60.20)	1.250	(31.75)	1.000	(25.40)	10,200	(4,627)	11,400	(5,171)	7.65	40.5	(44.55)	1.10
6-5	2.365	(60.07)	1.250	(31.75)	.992	(25.20)	10,000	(4,536)	11,200	(5,080)	7.64	39.7	(43.67)	1.08
6-6	2.365	(60.07)	1.250	(31.75)	.998	(25.35)	9,900	(4,491)	11,740	(5,325)	7.70	39.6	(43.56)	1.14
											Average	39.1	(43.01)	1.10

(a) K_Q values listed are invalid per ASTM E-399.

TABLE 22. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED A206-T7 ALUMINUM CASTING AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-4	70.0	(482.7)	150
8-5	60.0	(413.7)	2,420
8-2	50.0	(344.8)	54,857
8-11	45.0	(310.3)	49,800
8-1	40.0	(275.8)	140,658
8-3	35.0	(241.3)	367,344
8-14	30.0	(206.9)	9,506,463
	350 F (450 K)		
8-12	60.0	(413.7)	2
8-13	50.0	(344.8)	14,417
8-6	40.0	(275.8)	39,940
8-7	35.0	(241.3)	64,445
8-8	30.0	(206.9)	411,889
8-9	25.0	(172.4)	936,446
8-10	22.5	(155.1)	12,826,000 (b)

(a) Did not fail.

TABLE 23. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) A206-T7 ALUMINUM CASTING AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-17	50.0	(344.8)	2,091
8-18	40.0	(275.8)	4,129
8-19	30.0	(206.9)	9,896
8-20	20.0	(137.9)	88,818
8-22	15.0	(103.4)	211,585
8-23	10.0	(69.0)	2,766,597[(a)]
8-24	10.0	(69.0)	10,500,373[(b)]
	350 F (450 K)		
8-28	50.0	(344.8)	1,927
8-26	40.0	(275.8)	4,367
8-25	30.0	(206.9)	15,900
8-29	20.0	(137.9)	68,808
8-27	15.0	(103.4)	235,633
8-30	10.0	(69.0)	2,834,574
8-31	7.5	(51.7)	10,410,000[(b)]

(a) Machine problem -- was not maintaining set load.

(b) Did not fail.

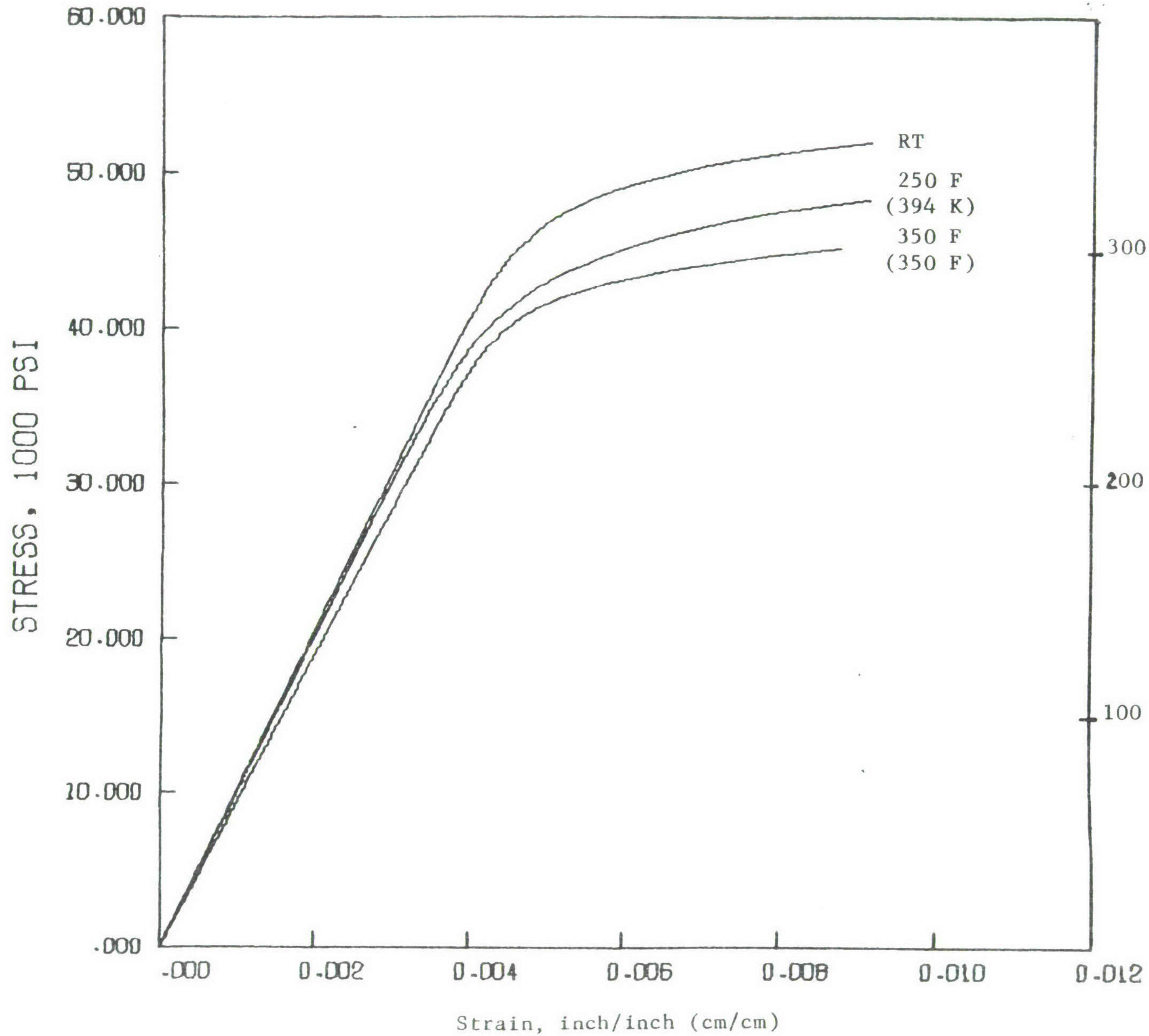

FIGURE 31. TYPICAL TENSILE STRESS-STRAIN CURVES FOR A206-T7 ALUMINUM CASTING.

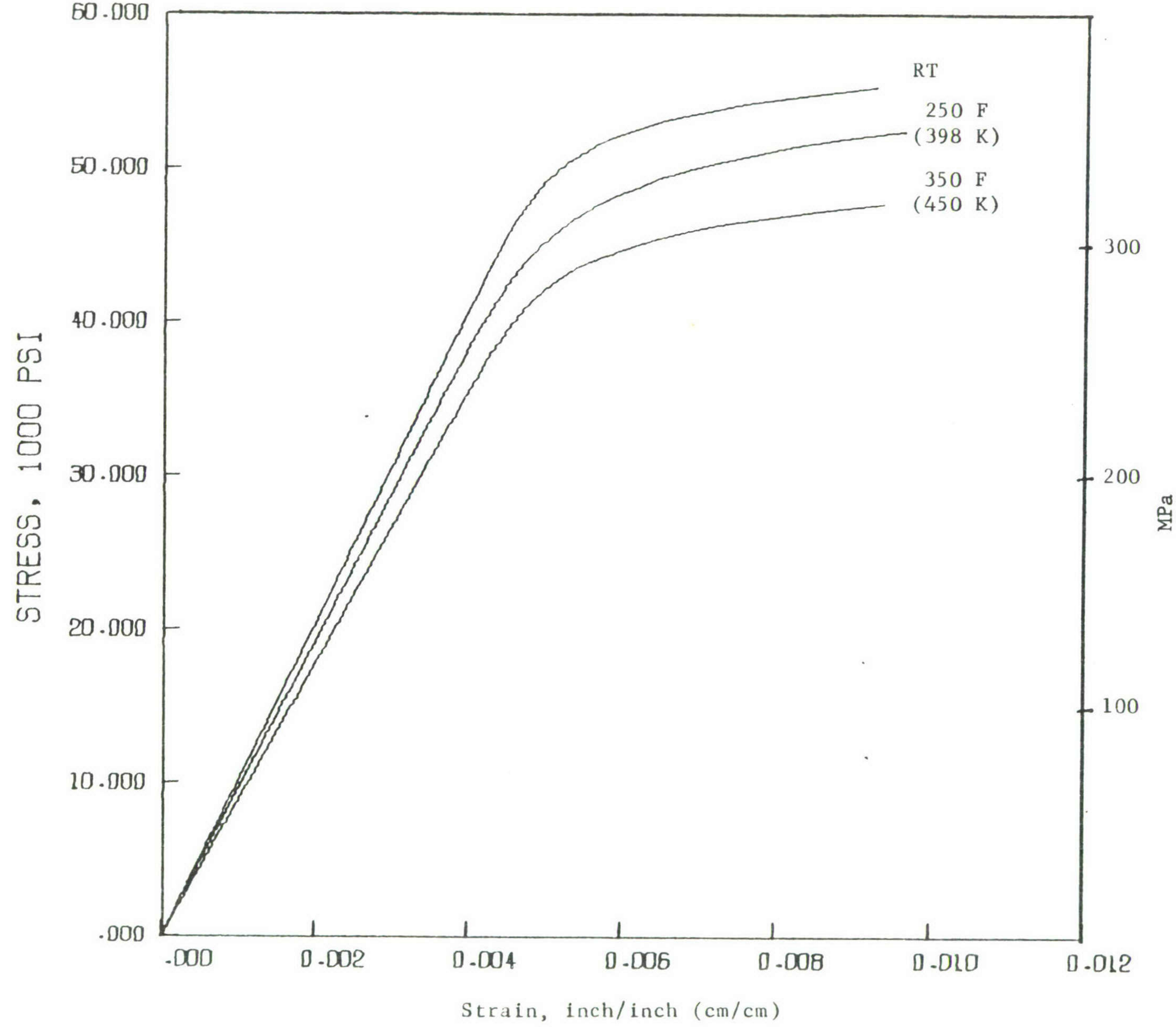

FIGURE 32. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR A206-T7 ALUMINUM CASTING.

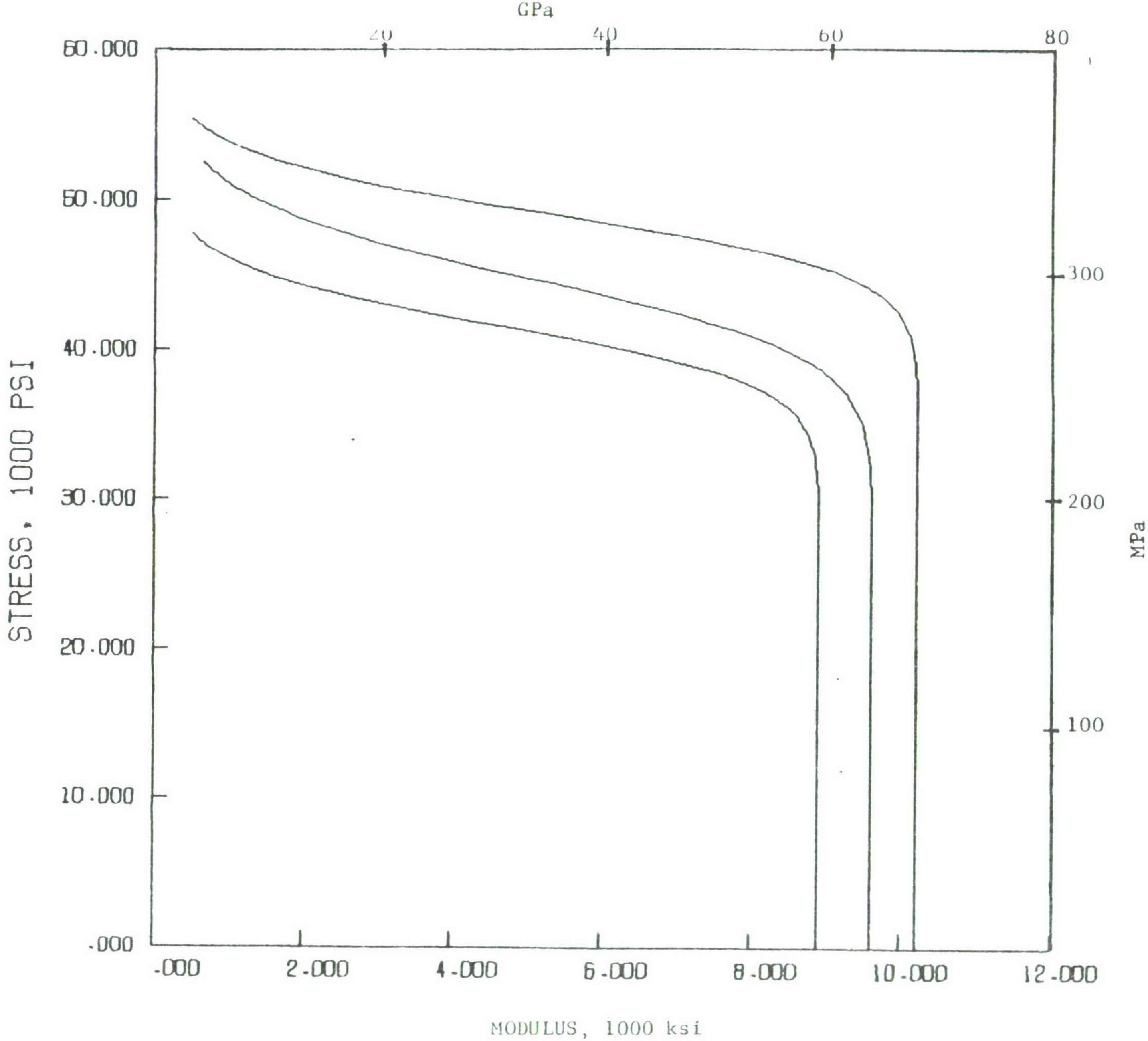

FIGURE 33. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR A206-T7 ALUMINUM CASTING

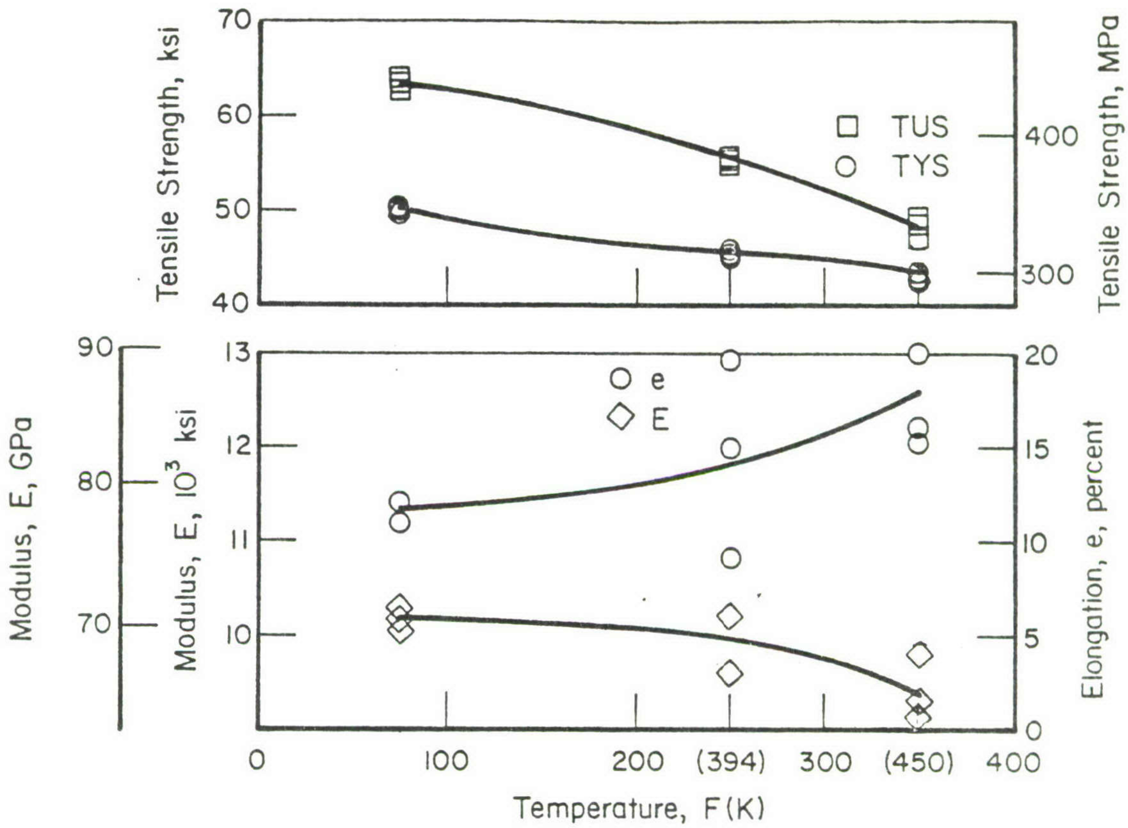

FIGURE 34. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF A 206-T7 ALUMINUM CASTING

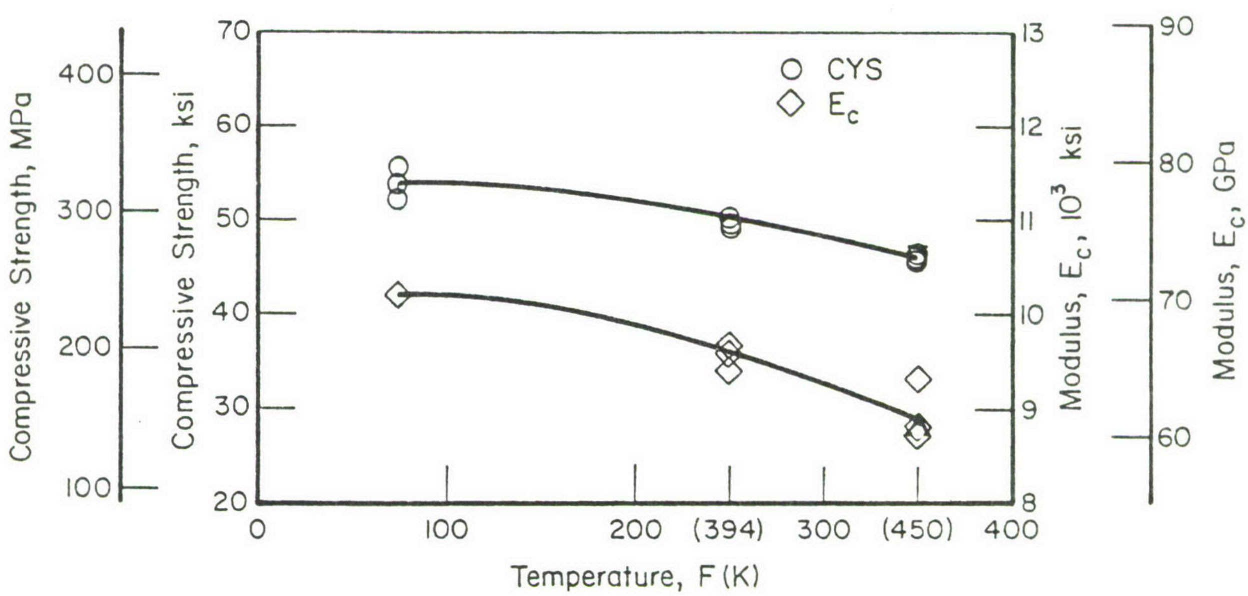

FIGURE 35. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF A 206-T7 ALUMINUM CASTING

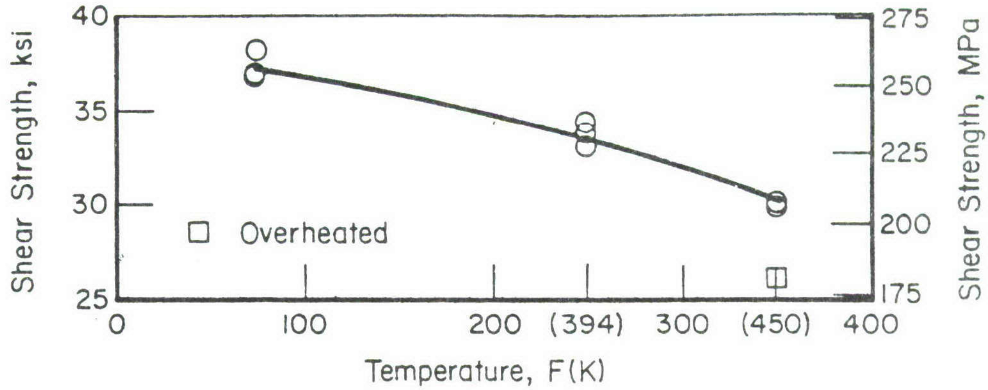

FIGURE 36. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF A 206-T7 ALUMINUM CASTING

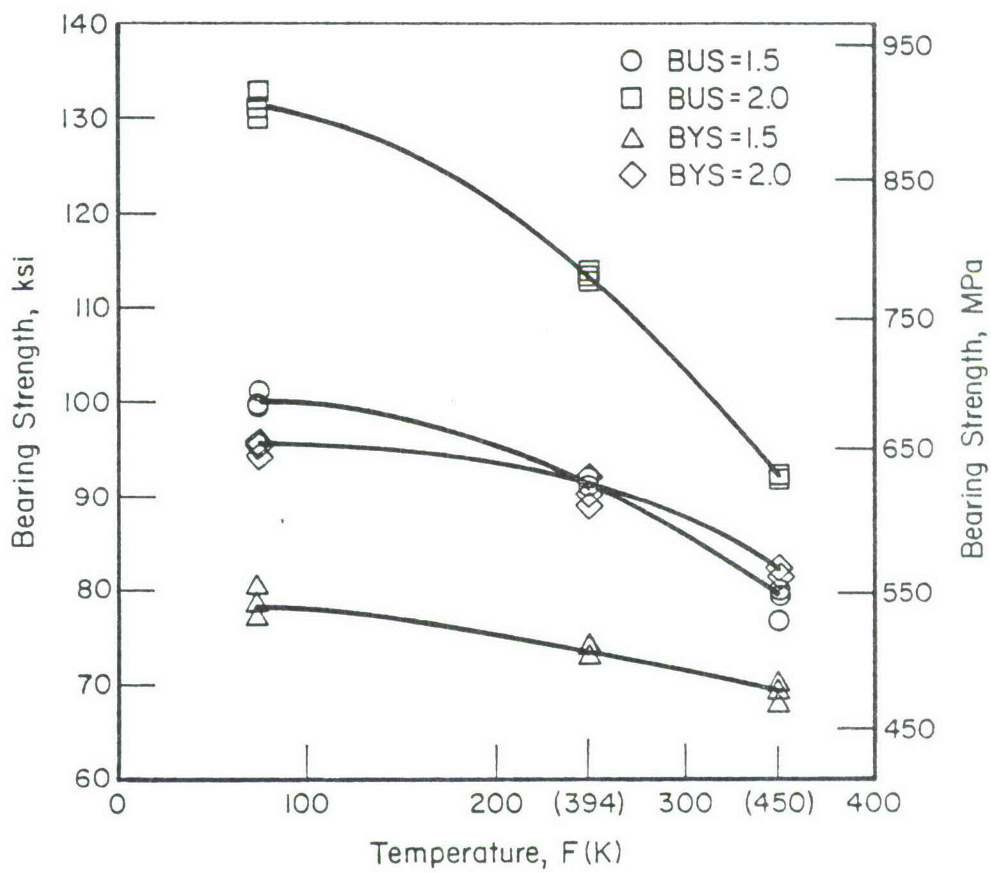

FIGURE 37. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF A 206-T7 ALUMINUM CASTING

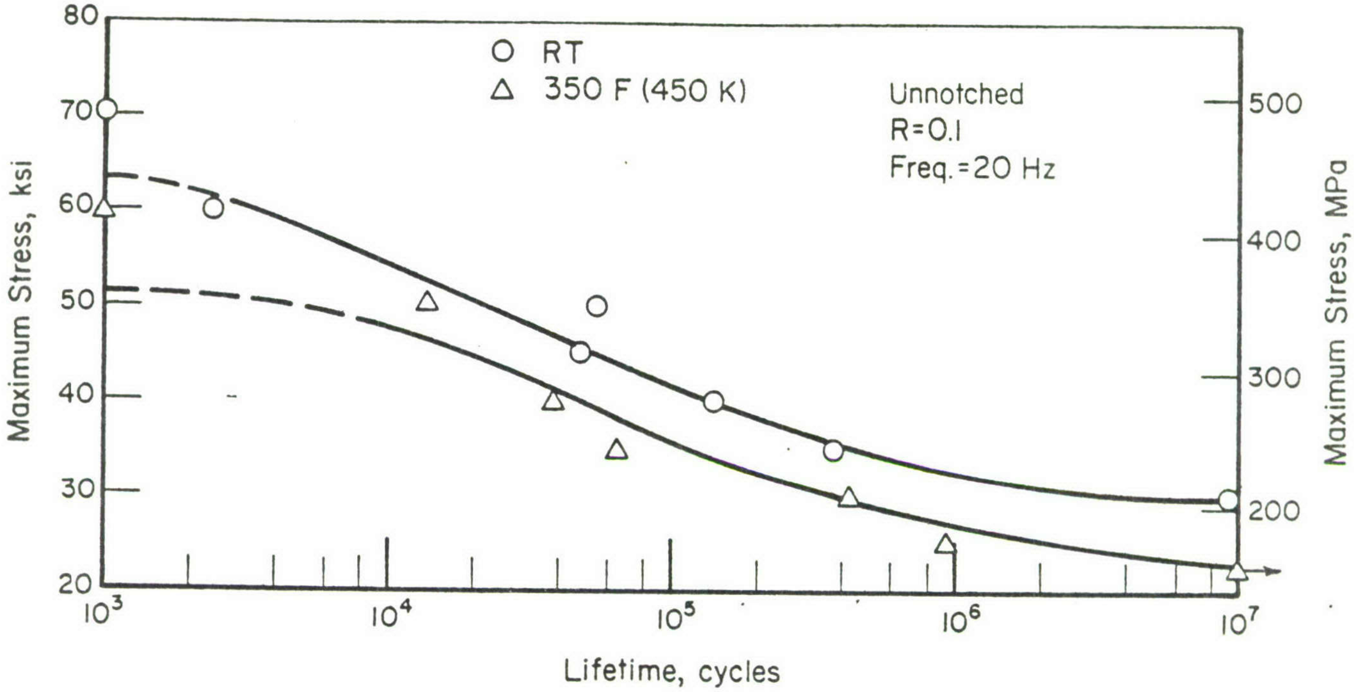

FIGURE 38. AXIAL LOAD BEHAVIOR OF UNNOTCHED A 206-T7 ALUMINUM CASTING

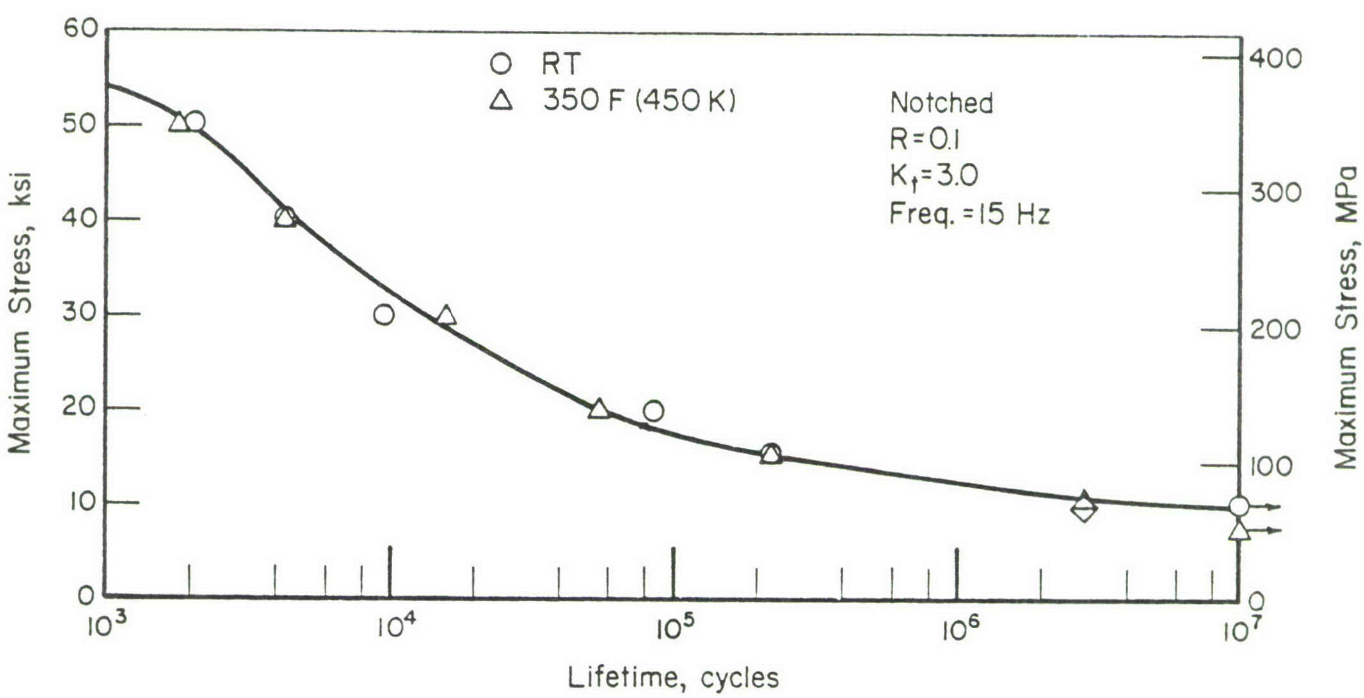

FIGURE 39. AXIAL LOAD BEHAVIOR OF NOTCHED A 206-T7 ALUMINUM CASTING

224.0-T6 Aluminum Castings

Material Description

Alloy 224 is a heat-treatable premium aluminum casting alloy. When solution heat treated and overaged, it possesses good mechanical properties at elevated temperatures. It also has good fatigue properties and toughness.

The material used in this evaluation was obtained through Eck Industries, Inc. as a swivel bracket casting. The composition is within the following:

Chemical Composition	Percent min. - max.
Cu	4.5 - 5.5
Mn	0.20 - 0.50
Zr	0.10 - 0.25
V	0.05 - 0.15
Ti	-- 0.35
Fe	-- 0.10
Si	-- 0.06
other impurities, total	0.10
Al	remainder

Processing and Heat Treating

The alloy was evaluated in the as-received -T6 condition. Specimens were machined from castings like the one pictured in Figure 40.

Test Results

Tension. Results of tension tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 24. Stress-strain curves at temperature are shown in Figure 41. Effect-of-temperature curves are presented in Figure 44.

Compression. Results of compression tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 25. Stress-strain and tangent-modulus curves are presented in Figures 42 and 43. Effect-of-temperature curves are shown in Figure 45.

Shear. Results of pin shear tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 26. Effect-of-temperature curves are shown in Figure 46.

Bearing. Results of bearing tests at room temperature are presented in Table 27. Due to limited material, only three specimens were made -- two with e/D = 1.5 and one with e/D = 2.0.

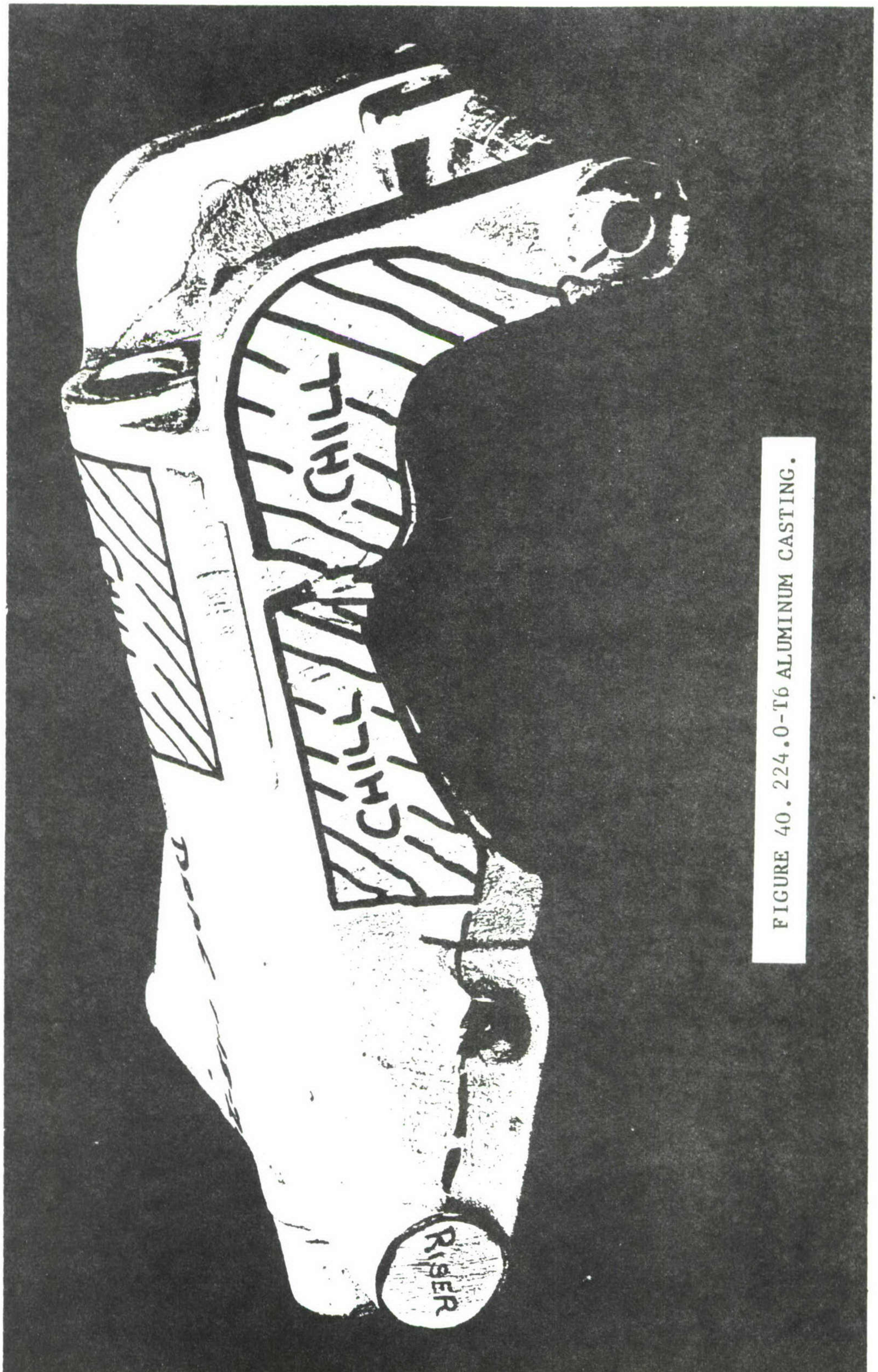

FIGURE 40. 224.0-T6 ALUMINUM CASTING.

Fatigue. Results of axial load fatigue tests for unnotched and notched specimens are given in Tables 28 and 29, respectively. Due to limited material, only specimens at room temperature were tested. S-N curves are presented in Figures 47 and 48.

Thermal Expansion. The coefficient of thermal expansion for this material is 10.7 in/in/F $\times 10^{-6}$ (RT to 212 F) [19.3 m/(m·k) $\times 10^{-6}$ (RT to 373 K)].

Density. The density is 0.102 lb/in^3 (2.823 g/cm^3).

TABLE 24. RESULTS OF TENSILE TESTS FOR 224.0-T6 ALUMINUM CASTINGS

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 1 Inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi	(GPa)
				Room Temperature				
1-1	55.9	(385.4)	31.2	(215.1)	17.0	18.9	9.5	(65.5)
1-2	52.0	(358.5)	28.3	(195.1)	13.0	15.0	10.2	(70.3)
1-3	51.2	(353.0)	30.5	(210.3)	10.0	13.4	10.1	(69.6)
Average	53.0	(365.7)	30.0	(206.9)	13.3	15.8	9.9	(68.3)
				250 F (394 K)				
1-4	40.5	(279.2)	27.2	(187.5)	14.0	28.2	9.4	(64.8)
1-5	38.8	(267.5)	23.6	(162.7)	18.0	36.4	9.5	(65.5)
1-6	46.5	(320.6)	29.2	(206.2)	16.0	26.4	9.3	(64.1)
Average	41.9	(289.1)	26.9	(185.5)	16.0	30.3	9.4	(64.8)
				350 F (450 K)				
1-7	39.7	(273.7)	30.2	(208.2)	14.0	14.9	10.3	(71.0)
1-8	33.6	(231.7)	23.6	(162.7)	15.0	38.1	9.7	(66.9)
1-9	37.2	(256.5)	26.6	(183.4)	14.0	24.2	8.2	(56.5)
Average	36.8	(254.0)	26.8	(184.8)	14.3	25.7	9.4	(64.8)

TABLE 25. RESULTS OF COMPRESSION TESTS FOR 224.0-T6 ALUMINUM CASTINGS

Specimen Number		0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(GPa)
		Room Temperature			
2-1		32.4	(223.4)	10.1	(69.3)
2-2		34.1	(235.1)	10.9	(75.2)
	Average	33.3	(229.6)	10.5	(72.4)
		250 F (394 K)			
2-4		30.4	(209.6)	8.2	(56.5)
2-5		32.3	(222.7)	8.4	(57.9)
2-6		32.6	(224.8)	9.2	(63.4)
	Average	31.8	(219.0)	8.6	(59.3)
		350 F (450 K)			
2-7		29.2	(201.3)	8.4	(57.9)
2-8		29.9	(206.2)	8.8	(60.7)
2-9		29.1	(200.6)	8.7	(60.0)
	Average	29.4	(202.7)	8.6	(59.5)

TABLE 26. PIN SHEAR TEST RESULTS FOR 224.0-T6 ALUMINUM CASTINGS

Specimen Number		Ultimate Shear Strength, ksi (MPa)
	Room Temperature	
3-1		36.5 (251.7)
3-2		34.2 (235.8)
3-3		34.9 (240.6)
	Average	35.2 (242.7)
	250 F (394 K)	
3-4		29.2 (201.3)
3-5		29.0 (200.0)
3-6		29.9 (206.2)
	Average	29.4 (202.5)
	350 F (450 K)	
3-7		24.1 (166.2)
3-8		24.1 (166.2)
3-9		24.1 (166.2)
	Average	24.1 (166.2)

TABLE 27. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR 224.0-T6 ALUMINUM CASTINGS

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0)
		Room Temperature		
4-1	92.3 (636.4)	106.3 (732.9)	60.6 (417.8)	71.4 (492.3)
4-2	90.9 (626.8)	--	63.1 (435.1)	--
Average	91.6 (631.6)	106.3 (732.9)	61.9 (426.5)	71.4 (492.3)

TABLE 28. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED 224.0-T6 ALUMINUM CASTINGS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-4	50	(344.8)	6,300
8-2	40	(275.8)	7,700
8-3	30	(206.9)	82,800
8-1	25	(172.4)	204,000
8-5	20	(137.9)	370,300
8-6	15	(103.4)	11,443,000 (a)

(a) Did not fail.

TABLE 29. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) 224.0-T6 ALUMINUM CASTINGS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-2	40	(275.8)	4,938
8-1	30	(206.9)	24,273
8-3	20	(137.9)	330,370
8-4	17.5	(120.7)	1,122,700
8-5	15.0	(103.4)	6,528,550

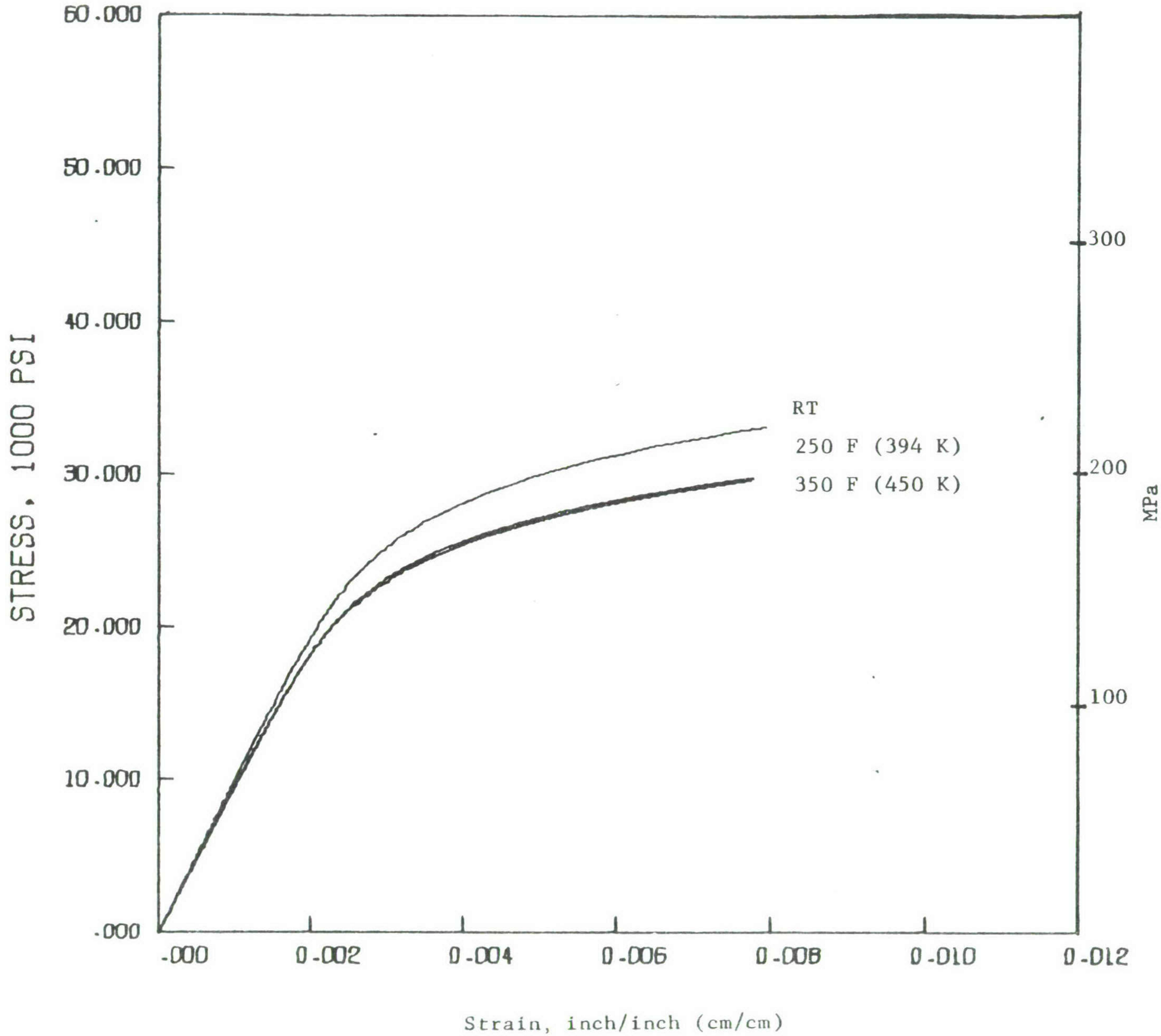

FIGURE 41. TYPICAL TENSILE STRESS-STRAIN CURVES FOR 224.0-T6 ALUMINUM CASTINGS AT TEMPERATURE

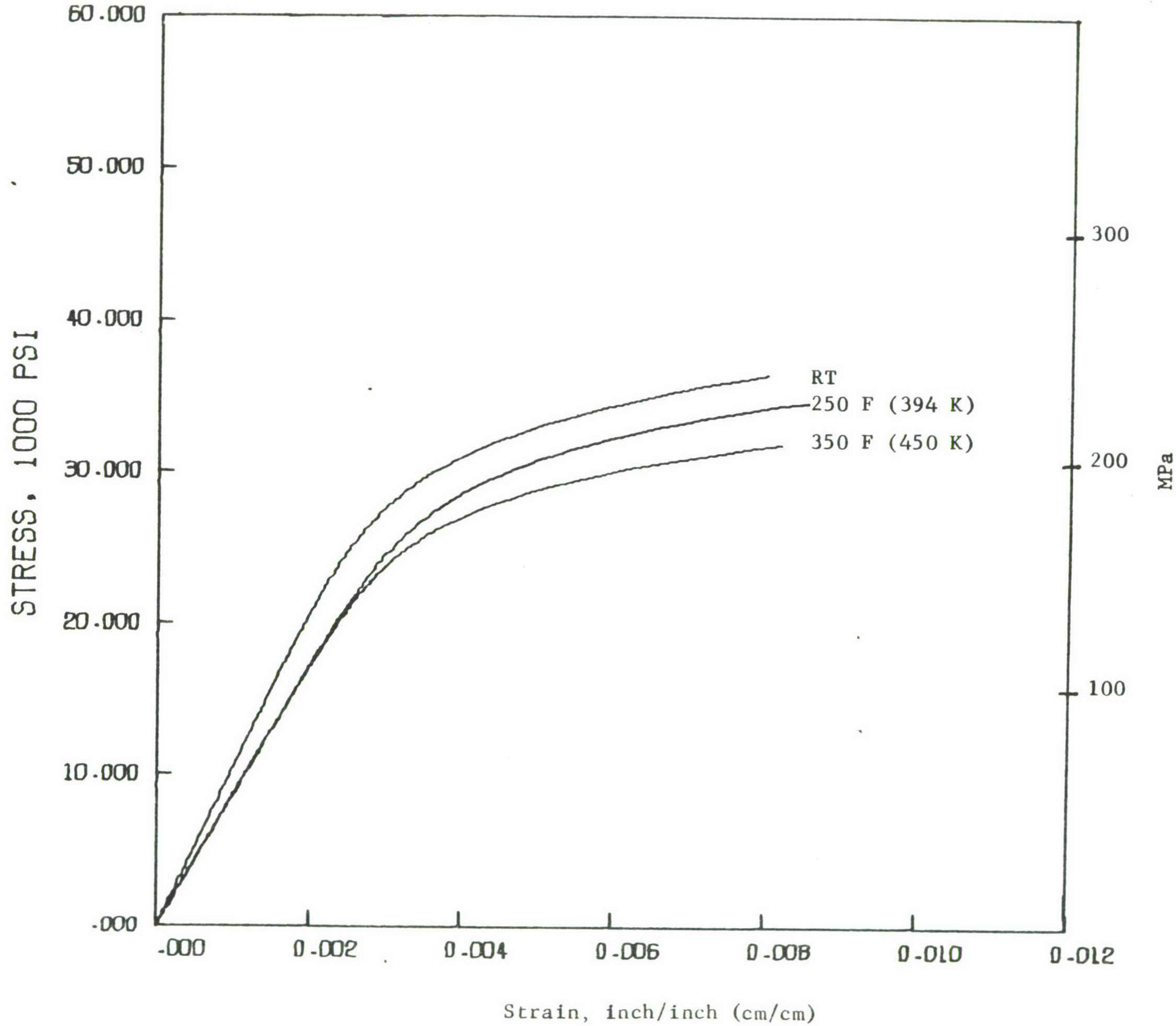

FIGURE 42. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR 224.0-T6 ALUMINUM CASTINGS AT TEMPERATURE

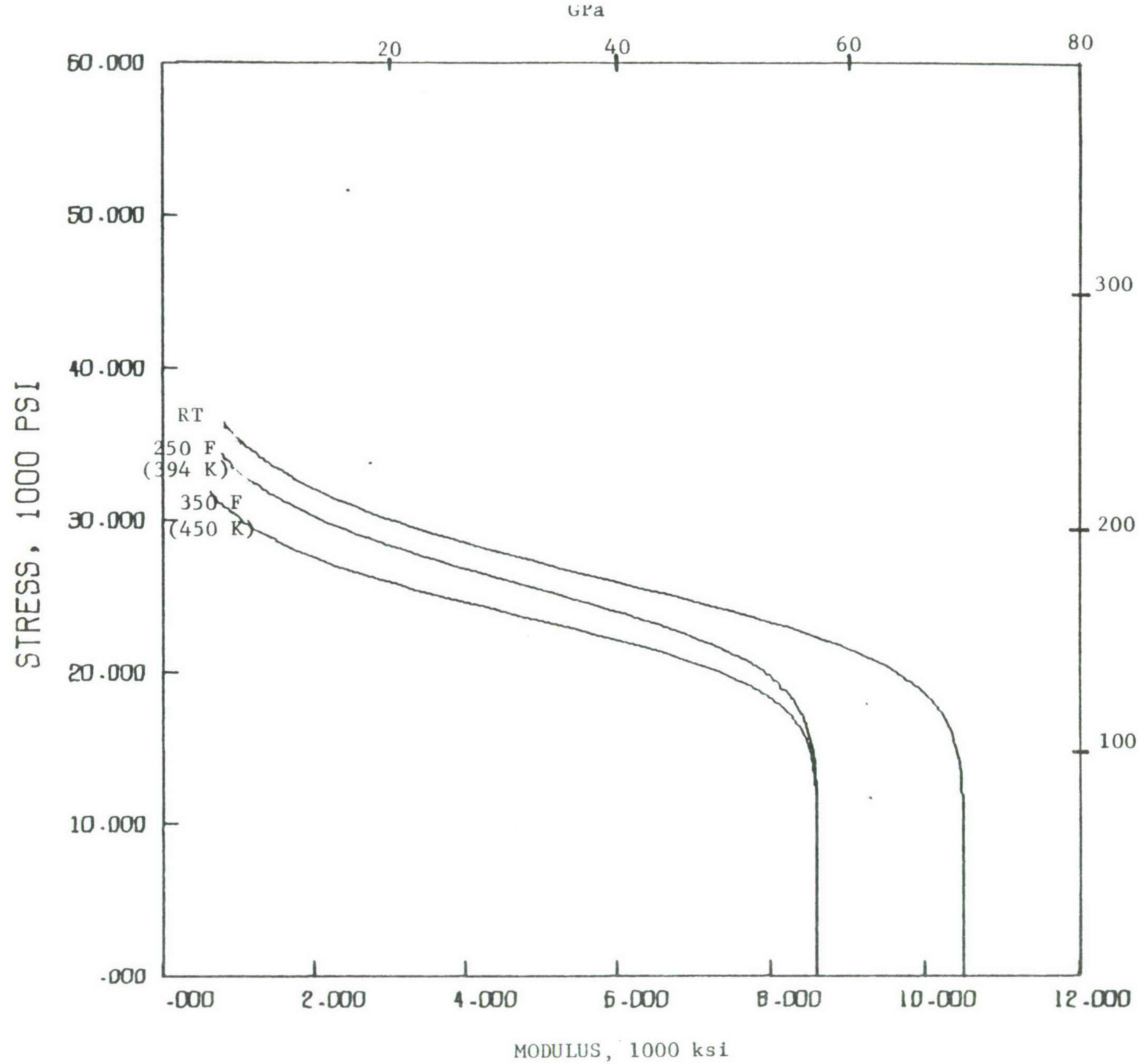

FIGURE 43. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR 224.0-T6 ALUMINUM CASTINGS AT TEMPERATURE

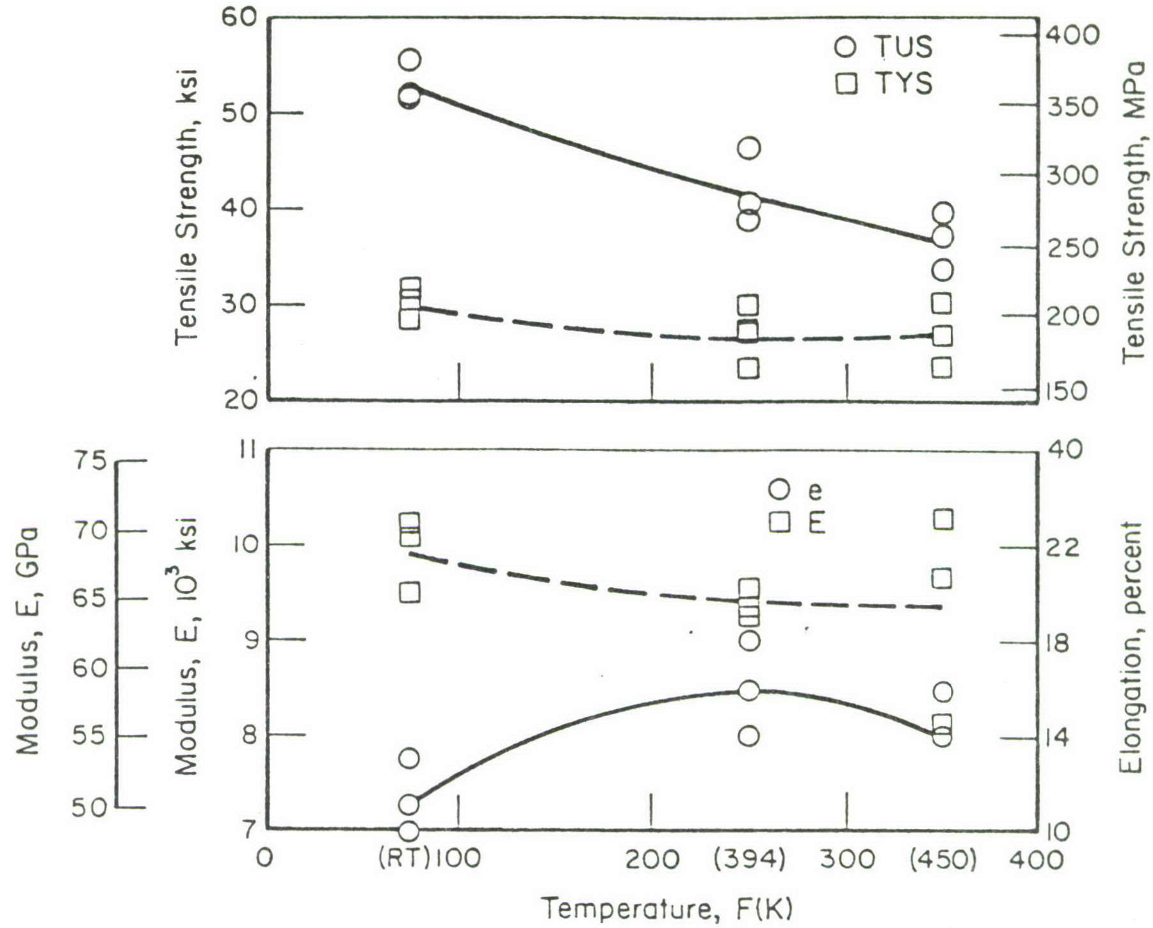

FIGURE 44. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 224.0-T6 ALUMINUM CASTINGS

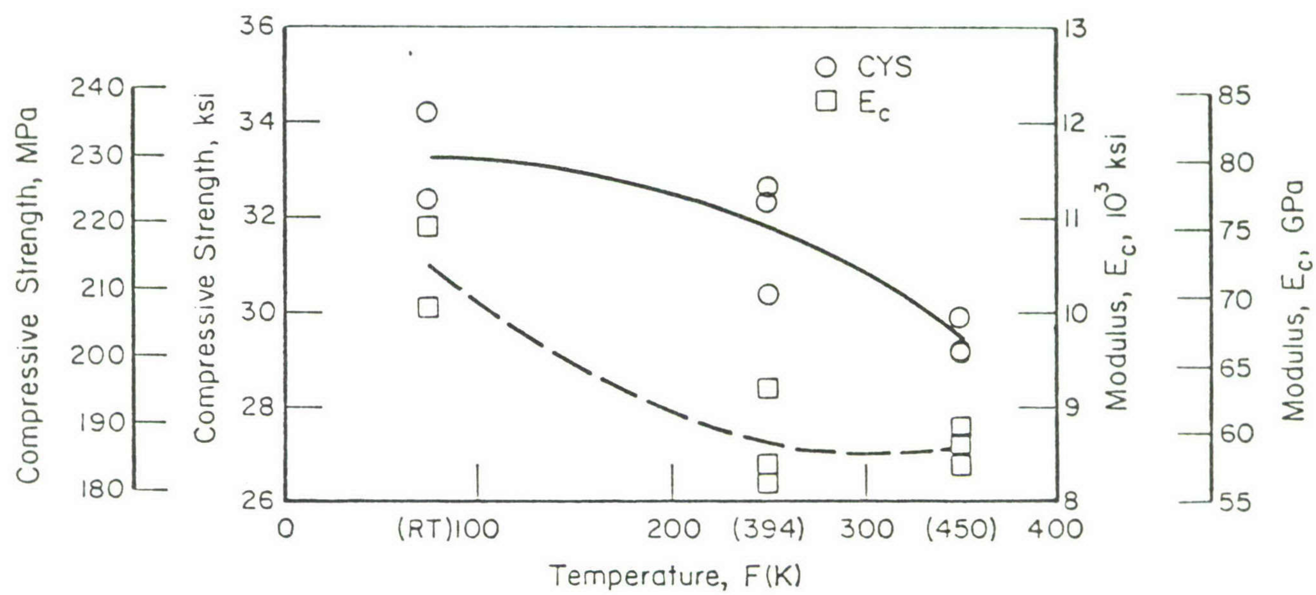

FIGURE 45. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 224.0-T6 ALUMINUM CASTINGS

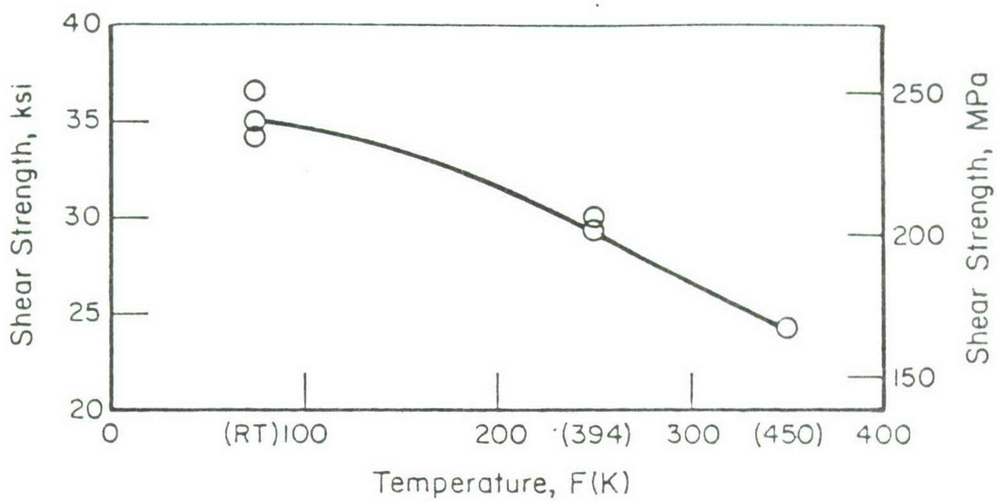

FIGURE 46. EFFECT OF TEMPERATURE ON PIN SHEAR PROPERTIES OF 224.0-T6 ALUMINUM CASTINGS

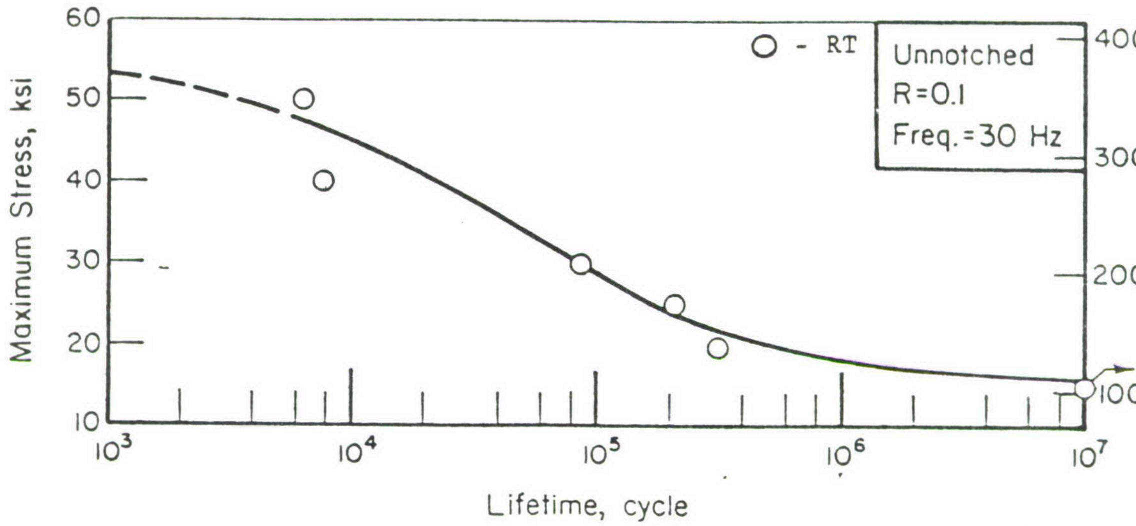

FIGURE 47. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 224.0-T6 ALUMINUM CASTINGS

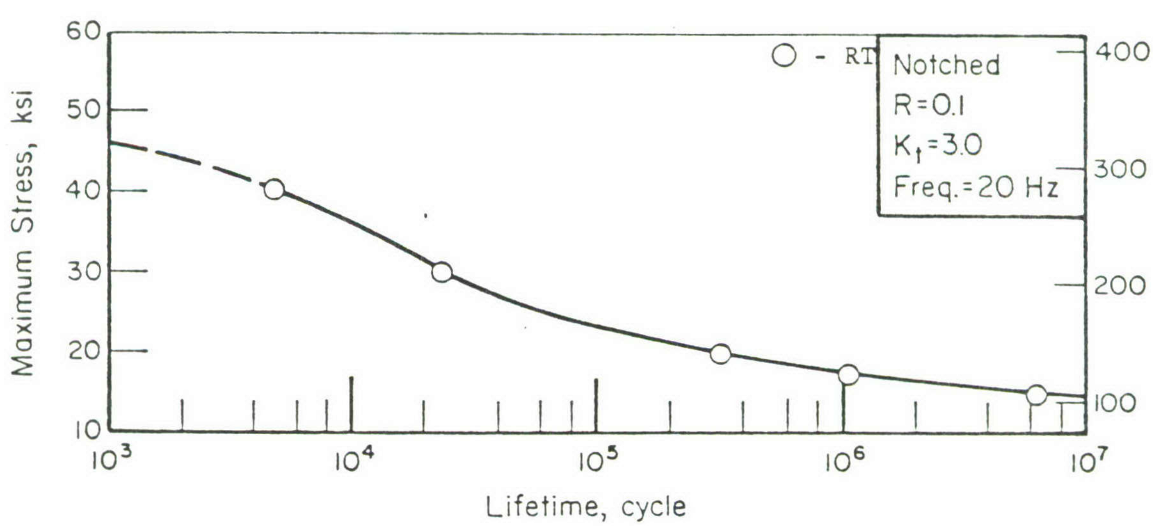

FIGURE 48. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) 224.0-T6 ALUMINUM CASTINGS

C355-T61 Cast Aluminum Alloy

Material Description

C355 alloy is similar to 355 aluminum alloy but C355 has the impurities controlled to lower limits, thus resulting in higher strengths.

The material used in this evaluation was obtained through Morris Bean and Company as impellers castings. The composition is within the following:

Chemical Composition	Percent, minimum - maximum
Cu	1.0 - 1.5
Si	4.5 - 5.5
Fe	0.20
Mg	0.4 - 0.6
Ti	0.20
Others	0.15
Al	Remainder

Processing and Heat Treating

The alloy was evaluated in the as-received -T61 condition. Specimens were machined from two small sizes of impellers. Due to material thickness limitations, some specimen types were not used.

Test Results

Tension. Results of tension tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 30. Typical stress-strain curves at temperature are presented in Figure 49. Effect-of-temperature curves are shown in Figure 52.

Compression. Results of compression tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 31. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 50 and 51. Effect-of-temperature curves are presented in Figure 53.

Shear. Pin shear test results at room temperature, 250 F (394 K), and 350 F (450 K) are presented in Table 32. Effect-of-temperature curves are shown in Figure 54.

Fatigue. Axial load fatigue test results for unnotched and notched specimens at room temperature and 350 F (450 K) are given in Tables 33 and 34, respectively. S-N curves are shown in Figures 55 and 56.

Thermal Expansion. The coefficient of thermal expansion of this material is 12.4 in/in/F x 10^{-6} (from RT to 212 F) [22.3 m/m · K x 10^{-6} (from RT to 373 K)].

Density. The density of this material is .098 lb./in^3 (2.71 g/cm^3).

TABLE 30. RESULTS OF TENSILE TESTS FOR C355-T61 ALUMINUM CASTINGS

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 1 Inch (25.4 mm), percent	Tensile Modulus, 10^3 ksi	(GPa)
			Room Temperature				
1-1	52.5	(362.0)	37.9	(261.3)	10	10.7	(73.8)
1-2	52.2	(359.9)	37.7	(259.9)	9	10.8	(74.5)
1-3	49.8	(343.4)	37.6	(259.3)	7	11.0	(75.8)
Average	51.5	(355.1)	37.7	(259.9)	9	10.8	(74.5)
			250 F (394 K)				
1-4	44.0	(303.4)	35.9	(247.5)	7	10.1	(69.6)
1-5	45.0	(310.3)	34.7	(239.3)	17	10.0	(69.0)
1-6	46.1	(317.9)	35.6	(245.5)	21	10.5	(72.4)
Average	45.0	(310.3)	35.4	(244.1)	15	10.2	(70.3)
			350 F (450 K)				
1-7	39.5	(272.4)	34.3	(236.5)	11	8.6	(59.3)
1-8	39.3	(271.0)	33.0	(227.5)	6	8.8	(60.7)
1-9	41.3	(284.8)	34.4	(237.2)	15	8.5	(58.6)
Average	40.0	(275.8)	33.9	(233.7)	11	8.6	(59.3)

TABLE 31. RESULTS OF COMPRESSION TESTS ON C355-T61 ALUMINUM CASTINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	(MPa)	Compression Modulus, 10^3 ksi	(GPa)
	Room Temperature			
2-1	38.7	(266.8)	8.9	(61.4)
2-2	39.8	(274.4)	9.9	(68.3)
2-3	39.7	(273.7)	9.1	(62.7)
Average	39.4	(271.7)	9.3	(64.1)
	250 F (394 K)			
2-4	38.0	(262.0)	9.0	(62.1)
2-5	37.8	(260.6)	9.4	(64.8)
2-6	38.1	(262.7)	8.5	(58.6)
Average	38.0	(261.8)	9.0	(62.0)
	350 F (450 K)			
2-7	35.0	(241.3)	8.9	(61.4)
2-8	35.0	(241.3)	8.9	(61.4)
2-9	35.1	(242.0)	9.2	(63.4)
Average	35.0	(241.6)	9.0	(62.1)

TABLE 32. PIN SHEAR TEST RESULTS FOR C355-T61 ALUMINUM CASTINGS

Specimen Number		Ultimate Shear Strength, ksi (MPa)
	Room Temperature	
3-1		33.1 (228.2)
3-2		32.6 (224.8)
3-3		33.4 (230.3)
	Average	33.0 (227.5)
	250 F (394 K)	
3-4		29.3 (202.0)
3-5		28.9 (199.3)
3-6		29.0 (200.0)
	Average	29.1 (200.6)
	350 F (450 K)	
3-7		24.3 (167.5)
3-8		24.2 (166.9)
3-9		24.2 (166.9)
	Average	24.2 (166.9)

TABLE 33. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED C355-T61 ALUMINUM CASTINGS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-2	50.0	(344.8)	2,184
8-3	42.5	(293.0)	39,957
8-1	35.0	(241.3)	62,363
8-4	25.0	(172.4)	1,095,640
8-5	22.5	(155.1)	1,507,480
8-6	20.0	(137.9)	166,558
8-7	10.0	(69.0)	10,023,372 (a)
	350 F (450 K)		
8-9	40.0	(275.8)	412
8-10	30.0	(206.9)	103,463
8-12	25.0	(172.4)	616,643
8-11	20.0	(137.9)	2,619,950
8-8	15.0	(103.4)	10,201,431 (a)

(a) Did not fail.

TABLE 34. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) C355-T61 ALUMINUM CASTINGS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-21	35.0	(241.3)	4,500
8-20	25.0	(172.4)	37,821
8-22	20.0	(137.9)	56,616
8-23	15.0	(103.4)	241,503
8-24	12.5	(86.2)	741,078
8-25	10.0	(69.0)	11,350,000[(a)]
	350 F (450 K)		
8-27	30.0	(206.9)	12,150
8-31	25.0	(172.4)	22,271
8-26	20.0	(137.9)	92,492
8-30	15.0	(103.4)	139,041
8-28	12.5	(86.2)	467,000
8-29	10.0	(69.0)	7,646,056

(a) Did not fail.

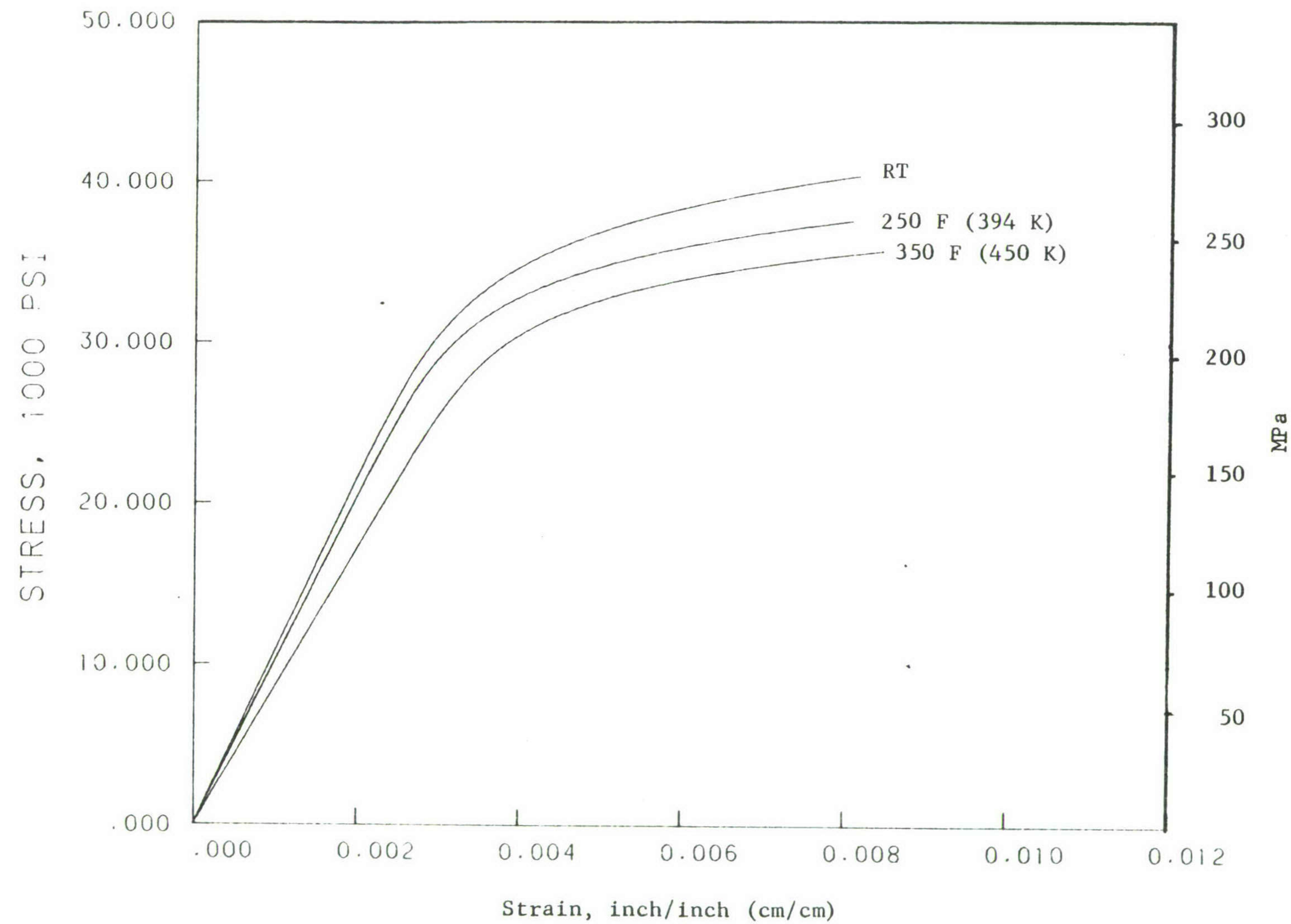

FIGURE 49. TYPICAL TENSILE STRESS-STRAIN CURVES FOR C355-T61 ALUMINUM CASTINGS AT TEMPERATURE

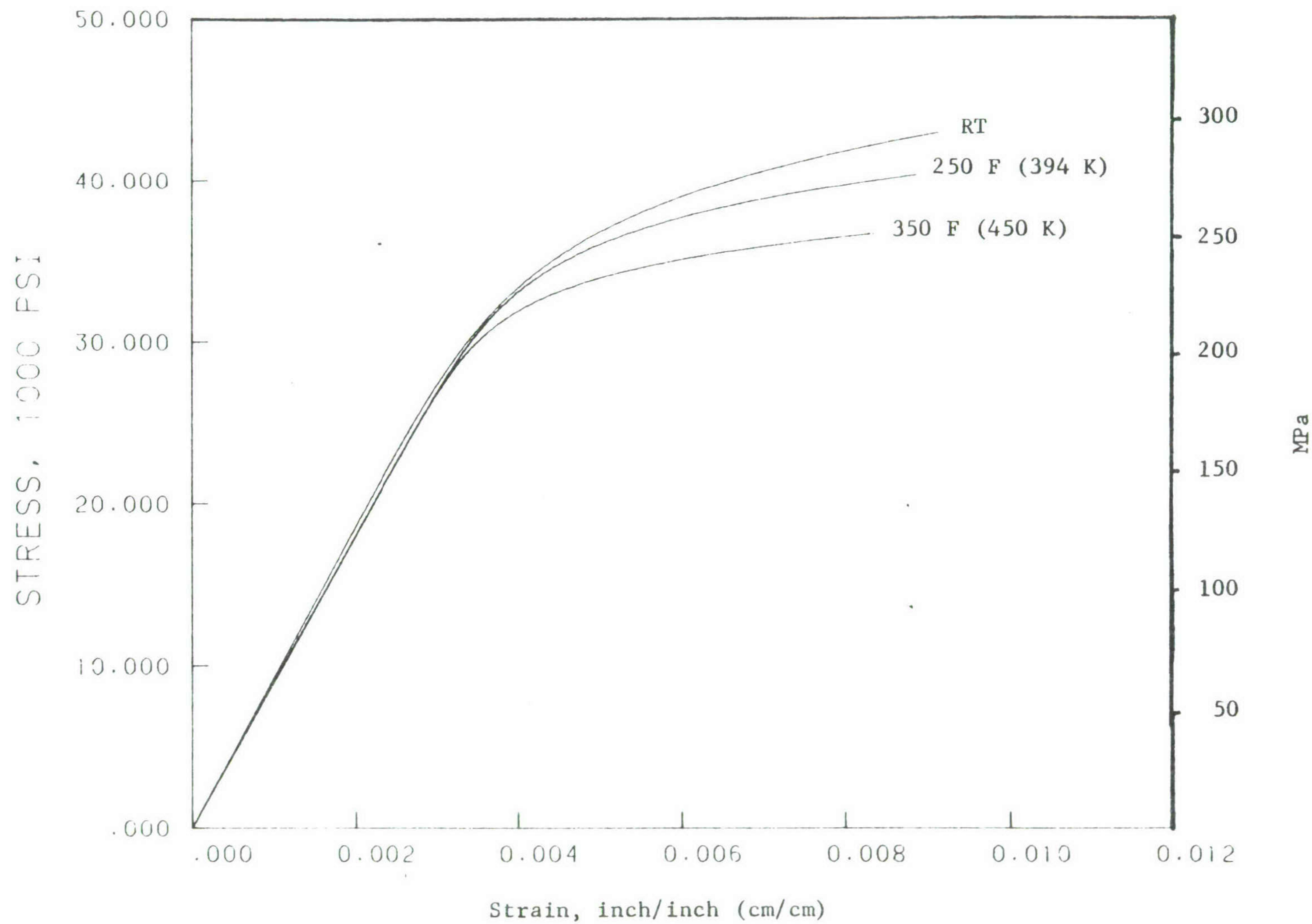

FIGURE 50. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR C355-T61 ALUMINUM CASTINGS AT TEMPERATURE

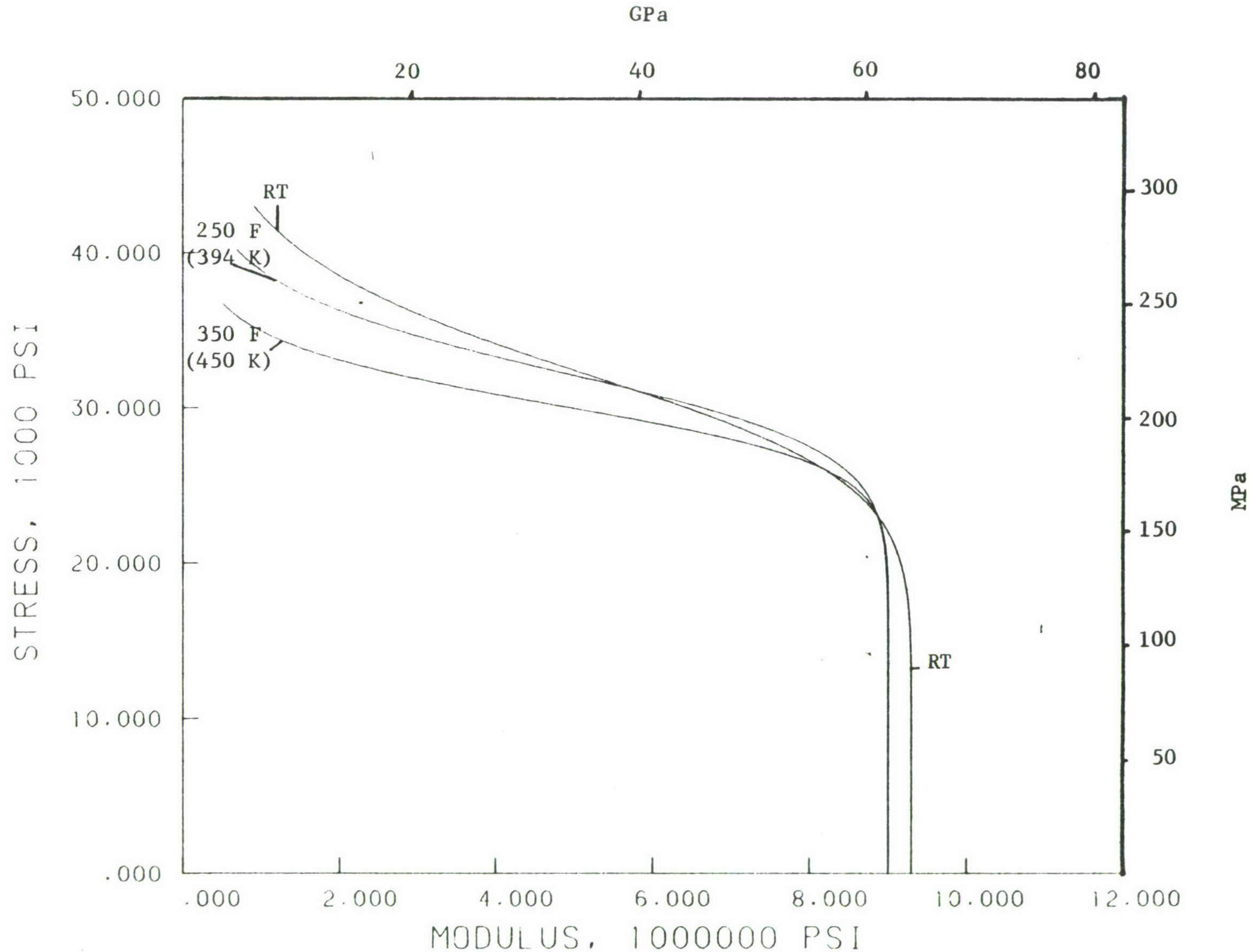

FIGURE 51. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR C355-T61 ALUMINUM CASTINGS AT TEMPERATURE

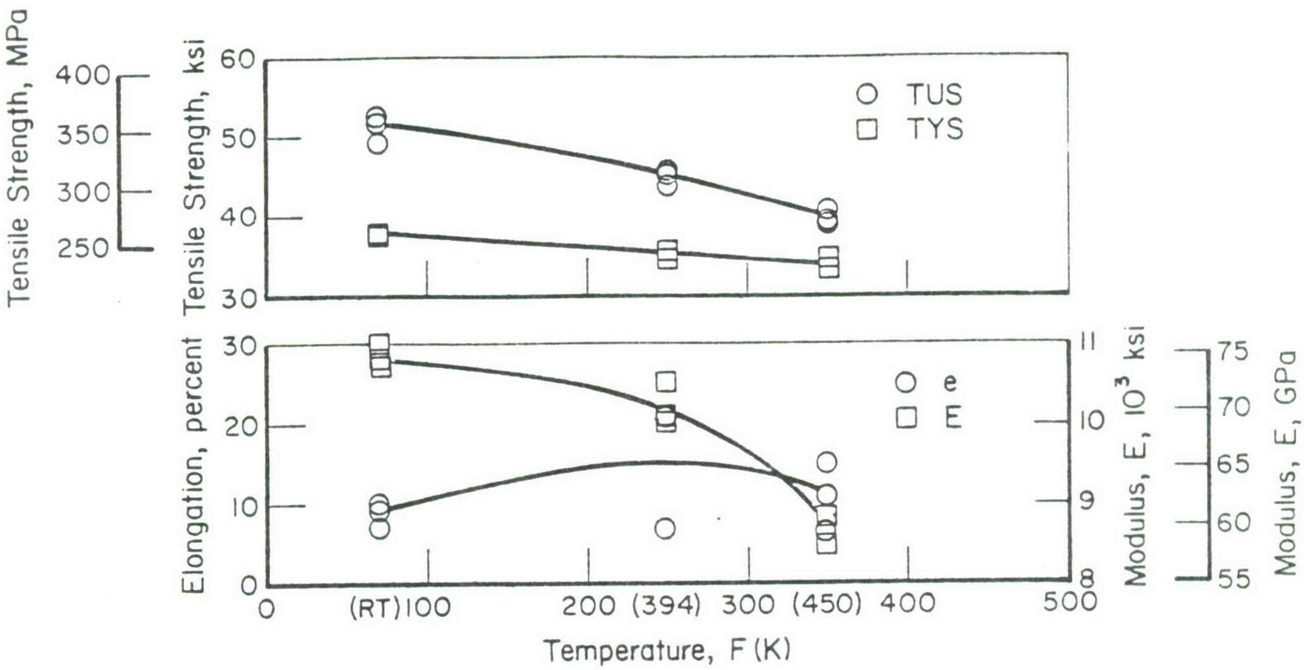

FIGURE 52. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF C355-T61 ALUMINUM CASTING

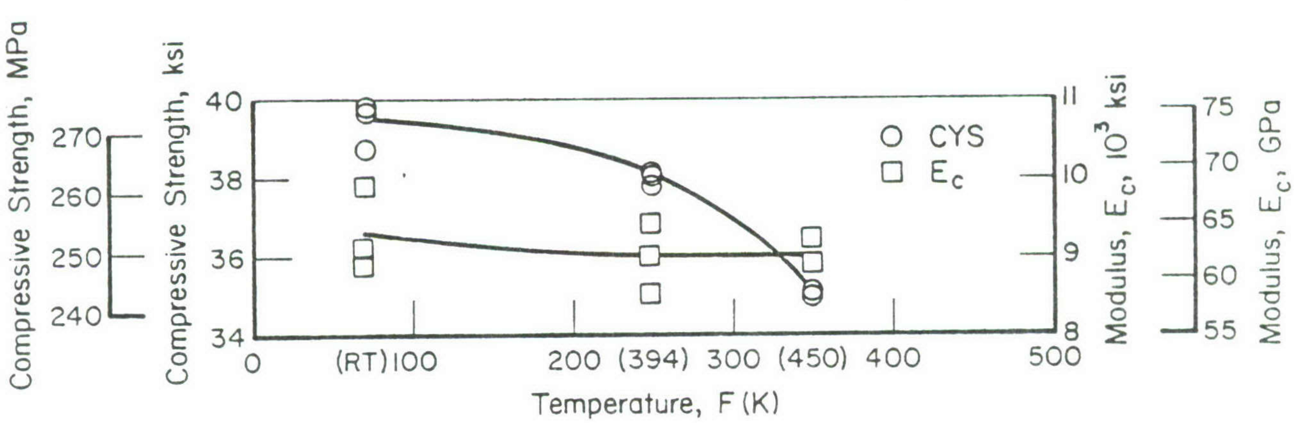

FIGURE 53. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF C355-T61 ALUMINUM CASTING

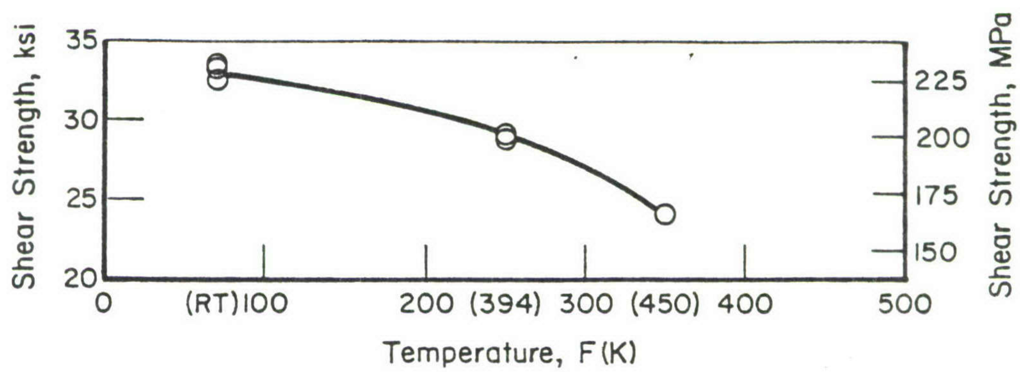

FIGURE 54. EFFECT OF TEMPERATURE ON SHEAR PROPERTIES OF C355-T61 ALUMINUM CASTING

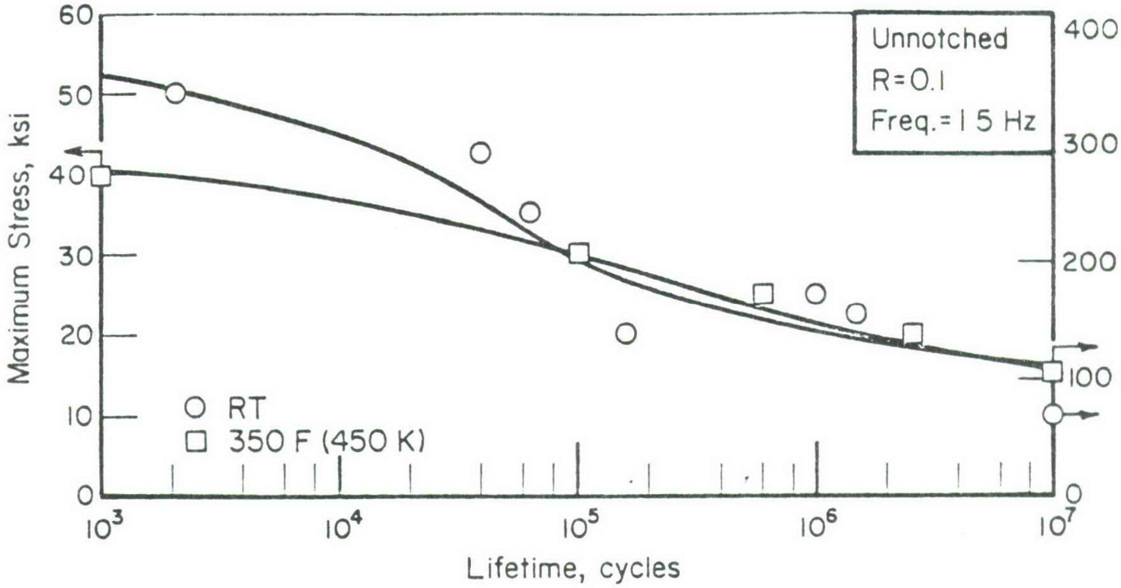

FIGURE 55. AXIAL LOAD BEHAVIOR OF UNNOTCHED C355-T61 ALUMINUM CASTING

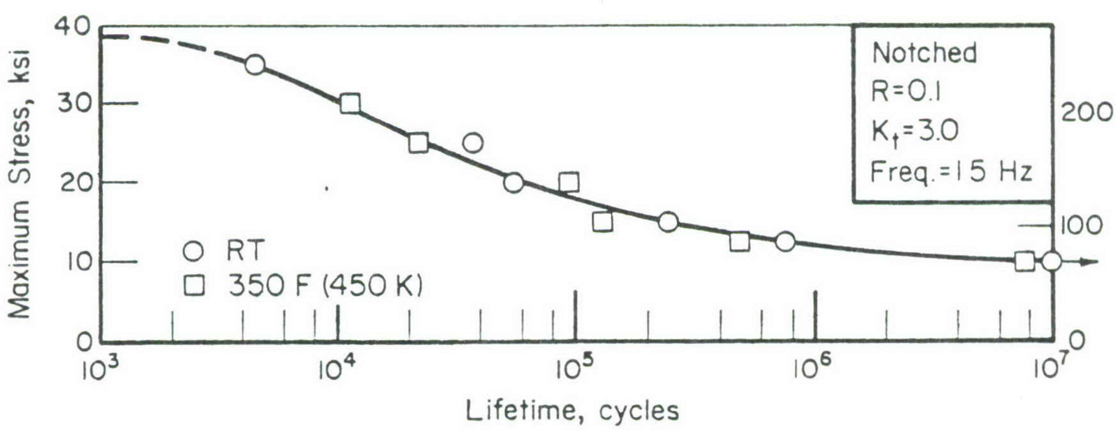

FIGURE 56. AXIAL LOAD BEHAVIOR OF NOTCHED C355-T61 ALUMINUM CASTING

Beta Processed Corona 5 Titanium Alloy

Material Description

Corona 5 is an alpha-beta alloy recently developed by Colt Industries and designed primarily for application in the aerospace industry. The development aim was for an alloy with toughness values above minimum required levels for fracture controlled titanium alloy parts.

The material evaluated was supplied GFM as 2-inch thick plate with the following composition:

Chemical Composition	Percent
Al	4.4
Mo	5.1
Cr	1.46
Fe	0.20
C	0.065
O_2	0.183
N_2	0.011
H_2	0.0018
Ti	Remainder

Processing and Heat Treating

The material was heat treated as follows: beta anneal 1525 F (1103 K), 4 hours, air cool plus age 1300 F (978 K), 6 hours, air cool. The specimen layout for this alloy is shown in Figure 57.

Test Results

Tension. Test results for both longitudinal and transverse specimens at room temperature, 400 F (477 K), and 800 F (700 K) are given in Table 35. Typical stress-strain curves at temperature are presented in Figures 58 and 59. Effect-of-temperature curves are shown in Figure 64.

Compression. Results of compression tests in both the longitudinal and transverse specimens at room temperature, 400 F (477 K), and 800 F (700 K) are given in Table 36. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 60 through 63. Effect-of-temperature curves are presented in Figure 65.

Shear. Pin shear test results for longitudinal and transverse specimens at room temperature, 400 F (477 K), and 800 F (700 K) are presented in Table 37. Effect-of-temperature curves are shown in Figure 66.

Bearing. Results of bearing tests on both longitudinal and transverse specimens at e/D = 1.5 and e/D = 2.0 at room temperature, 400 F (477 K), and 800 F (700 K) are presented in Table 38. Effect-of-temperature curves are shown in Figure 67.

Fracture Toughness. Results of compact tension type tests at room temperature for longitudinal (L-T) and transverse (T-L) specimens are given in Table 39. The candidate toughness values presented are invalid per ASTM E399 for the P_{max}/P_Q load ratio. Therefore R_{sc} values were calculated (per E399) and are presented in Table 39.

Fatigue. Axial load fatigue test results for transverse unnotched and notched (K_t = 3.0) specimens at room temperature and 800 F (700 K) are given in Tables 40 and 41. S-N curves are presented in Figures 68 and 69.

Creep and Stress Rupture. Results of transverse tests at 800 F (700 K) are given in Table 42. Log-stress versus log-time curves are shown in Figure 70.

Thermal Expansion. The coefficient of thermal expansion for this material is 6.1 in/in/F x 10^{-6} from RT to 800 F (11.0 m/m K x 10^{-6} RT - 700 K).

Density. The density of this alloy is 0.164 lb./in^3 (4.539 g/cm^3).

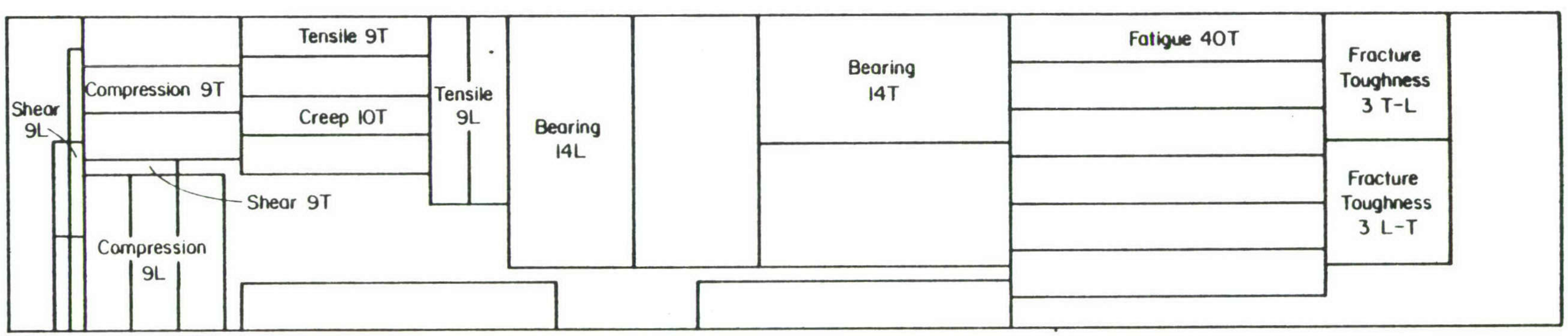

FIGURE 57. SPECIMEN LAYOUT FOR BETA-PROCESSED CORONA 5 TITANIUM

TABLE 35. TENSILE TEST RESULTS FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 1 Inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi	(GPa)
			Longitudinal at Room Temperature					
1L-1	139.7	(963.2)	131.3	(905.3)	12.0	16.5	16.1	(111.0)
1L-2	139.6	((62.5)	130.6	(900.5)	13.0	14.7	15.9	(108.9)
1L-3	138.6	(955.6)	129.7	(894.3)	13.0	19.8	16.1	(111.0)
Average	139.3	(960.5)	130.5	(900.0)	12.7	17.0	16.0	(110.3)
			Transverse at Room Temperature					
1T-1	139.7	(963.2)	131.3	(905.3)	16.0	23.3	16.4	(113.1)
1T-2	139.6	(962.5)	133.1	(917.7)	11.0	16.2	17.2	(118.6)
1T-3	138.6	(955.6)	133.0	(917.0)	13.0	23.4	16.9	(116.5)
Average	139.3	(960.5)	132.5	(913.4)	13.3	21.0	16.8	(116.1)
			Longitudinal at 400 F (477 K)					
1L-4	110.4	(761.2)	93.8	(646.8)	21.0	46.3	16.0	(110.3)
1L-5	112.9	(778.4)	94.6	(652.3)	18.0	46.6	17.5	(120.7)
1L-6	110.9	(764.7)	93.5	(644.7)	19.5	49.5	15.5	(106.9)
Average	111.4	(768.1)	94.0	(647.9)	19.5	47.5	16.3	(112.6)
			Transverse at 400 F (477 K)					
1T-4	116.6	(804.0)	99.5	(686.1)	19.0	44.8	15.5	(106.9)
1T-5	114.4	(788.8)	98.1	(676.4)	16.0	48.4	16.0	(110.3)
1T-6	114.3	(788.1)	97.7	(673.6)	18.0	43.7	16.8	(115.8)
Average	115.1	(793.6)	98.4	(678.7)	17.7	45.6	16.1	(111.0)
			Longitudinal at 800 F (700 K)					
1L-7	97.2	(670.4)	76.5	(527.6)	20	60.2	12.9	(88.9)
1L-8	95.8	(660.9)	77.4	(533.5)	17	55.5	13.4	(92.4)
1L-9	96.1	(662.3)	76.5	(527.6)	22	72.3	12.4	(85.5)
Average	96.4	(664.5)	76.8	(529.5)	19	62.7	12.9	(88.9)
			Transverse at 800 F (700 K)					
1T-7	94.2	(649.2)	76.8	(529.3)	16	55.7	13.1	(90.3)
1T-8	97.5	(672.5)	81.8	(563.9)	16	56.5	14.2	(97.9)
1T-9	97.6	(672.5)	79.4	(547.3)	16	57.1	14.1	(97.2)
Average	96.4	(664.8)	79.3	(546.8)	16	56.4	13.8	(95.2)

TABLE 36. COMPRESSION TEST RESULTS FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY

Specimen Number		0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(MPa)
		Longitudinal at Room Temperature			
2L-1		140.6	(969.4)	16.5	(113.8)
2L-2		137.6	(948.8)	17.2	(118.6)
2L-3		136.9	(943.9)	17.3	(119.3)
	Average	138.4	(954.0)	17.0	(117.2)
		Transverse at Room Temperature			
2T-1		146.7	(1011.5)	17.0	(117.2)
2T-2		146.7	(1011.5)	17.4	(120.0)
2T-3		142.5	(982.5)	17.1	(117.9)
	Average	145.3	(1001.8)	17.2	(118.4)
		Longitudinal at 400 F (477 K)			
2L-4		96.9	(668.1)	14.6	(100.7)
2L-5		97.2	(670.2)	15.2	(104.8)
2L-6		97.5	(672.3)	14.7	(101.4)
	Average	97.2	(670.2)	14.8	(102.3)
		Transverse at 400 F (477 K)			
2T-4		103.9	(716.4)	15.0	(103.4)
2T-5		101.0	(696.4)	15.6	(107.6)
2T-6		101.2	(697.8)	14.9	(102.7)
	Average	102.0	(703.5)	15.2	(104.6)
		Longitudinal at 800 F (700 K)			
2L-7		78.2	(539.2)	13.8	(95.2)
2L-8		78.0	(537.2)	12.4	(85.5)
2L-9		78.8	(543.3)	14.1	(97.2)
	Average	78.3	(540.1)	13.4	(92.6)
		Transverse at 800 F (700 K)			
2T-7		83.1	(573.0)	13.9	(95.8)
2T-8		82.6	(569.5)	13.6	(93.8)
2T-9		83.1	(573.0)	13.5	(93.1)
	Average	82.9	(571.8)	13.7	(94.2)

TABLE 37. RESULTS OF SHEAR PIN TESTS FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY

Specimen Number	Ultimate Shear Strength, ksi	(MPa)
Longitudinal at Room Temperature		
3L-1	89.94	(620.1)
3L-2	88.02	(606.9)
3L-3	91.03	(627.7)
Average	89.66	(618.2)
Transverse at Room Temperature		
3T-1	91.43	(630.4)
3T-2	89.95	(620.2)
3T-3	89.94	(620.1)
Average	90.44	(623.6)
Longitudinal at 400 F (477 K)		
3L-4	77.52	(534.5)
3L-5	71.70	(494.4)
3L-6	76.13	(524.9)
Average	75.12	(517.9)
Transverse at 400 F (477 K)		
3T-4	74.16	(511.3)
3T-5	73.55	(507.1)
3T-6	73.42	(506.2)
Average	73.71	(508.2)
Longitudinal at 800 F (700 K)		
3L-7	63.10	(435.1)
3L-8	63.05	(434.7)
3L-9	61.36	(423.1)
Average	62.50	(431.0)
Transverse at 800 F (700 K)		
3T-7	61.16	(421.7)
3T-8	60.79	(419.2)
3T-9	61.41	(423.4)
Average	61.12	(421.4)

TABLE 38. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Bearing Yield Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
Longitudinal at Room Temperature				
4L-1	224.9 (1550.7)	285.5 (1968.5)	206.4 (1423.1)	235.0 (1620.3)
4L-2	223.4 (1540.3)	283.6 (1955.4)	198.1 (1365.9)	233.3 (1608.6)
4L-3	225.1 (1552.1)	281.3 (1939.6)	198.7 (1370.0)	232.1 (1600.3)
Average	224.5 (1547.7)	283.5 (1954.5)	201.1 (1386.4)	233.5 (1609.8)
Transverse at Room Temperature				
4T-1	226.1 (1559.0)	297.2 (2049.2)	196.6 (1355.6)	246.0 (1696.2)
4T-2	222.8 (1536.2)	289.0 (1992.7)	193.1 (1331.4)	235.5 (1623.8)
4T-3	230.2 (1587.2)	289.2 (1994.0)	200.2 (1380.4)	238.8 (1646.5)
Average	226.4 (1560.8)	291.8 (2012.0)	196.6 (1355.8)	240.1 (1655.5)
Longitudinal at 400 F (478 K)				
4L-4	186.4 (1285.2)	229.2 (1580.3)	152.5 (1051.5)	189.2 (1304.5)
4L-5	189.2 (1304.5)	230.7 (1590.7)	155.2 (1070.1)	187.6 (1293.5)
Average	187.8 (1294.9)	230.0 (1585.5)	153.9 (1060.8)	188.4 (1299.0)
Transverse at 400 F (478 K)				
4T-4	186.2 (1283.8)	243.7 (1680.3)	155.2 (1070.1)	193.7 (1335.6)
4T-5	185.1 (1276.3)	240.5 (1658.2)	153.9 (1061.1)	194.2 (1339.0)
Average	185.7 (1280.1)	242.1 (1669.3)	154.6 (1065.5)	194.0 (1337.3)
Longitudinal at 800 F (700 K)				
4L-6	159.9 (1102.5)	211.0 (1454.8)	128.5 (886.0)	154.5 (1065.3)
4L-7	162.1 (1117.7)	206.3 (1422.4)	131.9 (909.5)	155.7 (1073.6)
Average	161.0 (1110.1)	208.7 (1438.6)	130.2 (897.7)	155.1 (1069.4)
Transverse at 800 F (700 K)				
4T-6	162.6 (1121.1)	206.2 (1421.7)	130.8 (901.9)	155.9 (1074.9)
4T-7	162.0 (1117.0)	203.5 (1403.1)	131.8 (908.8)	154.6 (1066.0)
Average	162.3 (1119.1)	204.9 (1412.4)	131.3 (905.3)	155.3 (1070.4)

TABLE 39. FRACTURE TOUGHNESS TEST RESULTS FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT ROOM TEMPERATURE

Specimen Number	Width, W		Thickness B		a		P_q		R_{max}		$f(\frac{a}{W})$	K_q (a)		R_{sc}
	Inches	(m m)	Inches	(m m)	Inches	(m m)	lbs	(kg)	lbs	(kg)		ksi-in $\frac{1}{2}$	(MPa-m $\frac{1}{2}$)	
6L-1	1.499	(38.07)	0.746	(18.95)	0.580	(14.72)	12,725	(5772)	15,375	(6974)	0.387	98.7	(108.6)	1.34
6L-2	1.498	(38.05)	0.750	(19.05)	0.565	(14.35)	10,225	(4638)	15,900	(7212)	0.377	77.2	(85.5)	1.33
6L-3	1.499	(38.07)	0.749	(19.03)	0.561	(14.24)	12,000	(5443)	14,800	(6713)	0.374	89.8	(98.8)	1.22
											Average	88.6	(97.4)	1.30
6T-1	1.499	(38.07)	0.749	(19.03)	0.529	(13.44)	13,250	(6010)	19,875	(9015)	0.353	94.5	(104.0)	1.50
6T-2	1.500	(38.10)	0.749	(19.03)	0.548	(13.91)	12,375	(5613)	17,875	(8108)	0.365	90.7	(99.8)	1.41
6T-3	1.501	(38.13)	0.749	(19.03)	0.530	(13.46)	12,800	(5806)	20,675	(9378)	0.353	91.1	(100.2)	1.56
											Average	92.1	(101.3)	1.49

(a) K_q is invalid per ASTM E399.

TABLE 40. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR UNNOTCHED BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-21	110.0	(758.5)	3,280
8-17	107.5	(741.2)	86,940
8-19	100.0	(689.5)	1,834,150
8-23	97.5	(672.3)	6,570
8-25	97.5	(672.3)	542,200
8-27	95.0	(655.0)	967,810
8-29	85.0	(586.1)	6,980
8-31	85.0	(586.1)	174,900
8-32	72.5	(499.9)	10,000,000[a]
8-30	60.0	(413.7)	10,000,000[a]
	800 F (700 K)		
8-18	95.0	(655.0)	4,300
8-22	90.0	(620.6)	4,600
8-24	85.0	(586.1)	25,400
8-26	82.5	(568.8)	325,500
8-20	80.0	(551.6)	303,900
8-28	77.5	(534.4)	10,000,000[a]

(a) Did not fail.

TABLE 41. RESULTS OF AXIAL LOAD FATIGUE TESTS FOR NOTCHED (K_t = 3.0) BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	(MPa)	Cycles to Failure
	Room Temperature		
8-31	50.0	(344.8)	8,560
8-33	40.0	(275.8)	24,090
8-35	30.0	(206.9)	48,070
8-41	20.0	(137.9)	140,440
8-37	15.0	(103.4)	419,760
8-43	15.0	(103.4)	712,630
8-39	10.0	(69.0)	16,646,350[a]
	800 F (700 K)		
8-32	100.0	(689.5)	1,400
8-34	40.0	(275.8)	15,500
8-36	30.0	(206.9)	41,800
8-42	25.0	(172.4)	84,100
8-46	22.5	(155.1)	139,000
8-38	20.0	(137.9)	862,200
8-44	17.5	(120.7)	2,912,000
8-40	15.0	(103.4)	10,000,000[a]

(a) Did not fail.

TABLE 42. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY

Specimen Number	Stress, ksi (MPa)	Temperature F (K)	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr	Elongation in Inches (50.8 mm) percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0					
9-1	100 (690)	800 (700)	--	--	--	--	--	5.623	0.1	13.8	56.4	--
9-5	95 (655)	800 (700)	--	0.01	0.03	0.17	0.9	3.904	15.9	18.5	41.6	0.86
9-3	90 (621)	800 (700)	0.05	0.15	1.3	4.0	9.8	1.558	186.8	21.5	53.5	0.042
9-6	80 (552)	800 (700)	0.5	1.4	4.2	10.5	27	0.757	603.2	18.5	53.1	0.012
9-2	70 (483)	800 (700)	2.5	7	21	56		0.669	141.3[a]	2.212	--	
9-4	50 (345)	800 (700)	11	25	105	400[a]	--	0.311	140.1[b]	0.877	--	0.0010
9-7	20 (138)	800 (700)	15	150	1500[a]	--	--	0.131	475.1[b]	0.389	--	0.00075
9-8	10 (69)	800 (700)						0.085	167.0[a]		--	

(a) Estimated.
(b) Test discontinued.

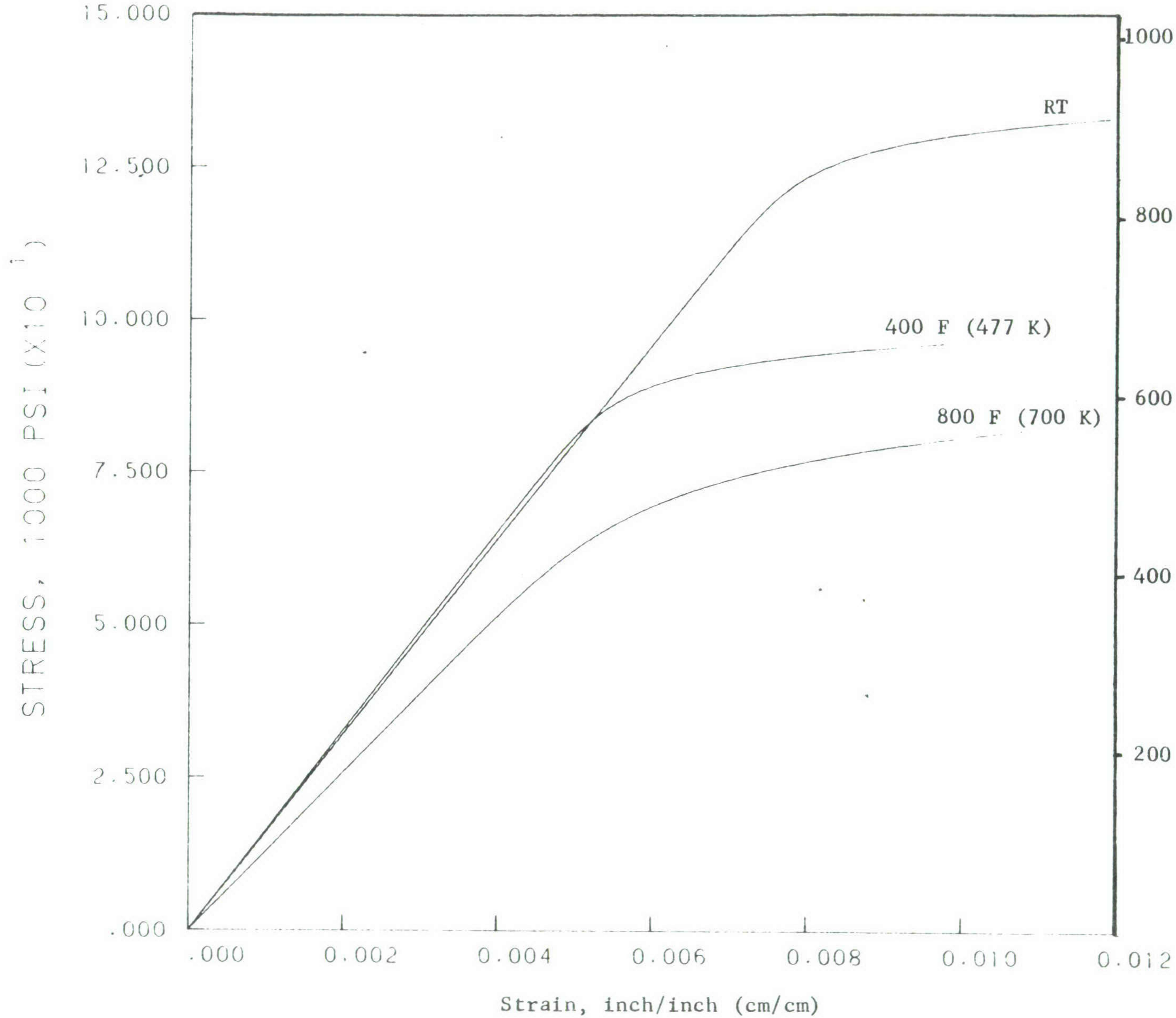

FIGURE 58. TYPICAL TENSILE STRESS-STRAIN CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (LONGITUDINAL)

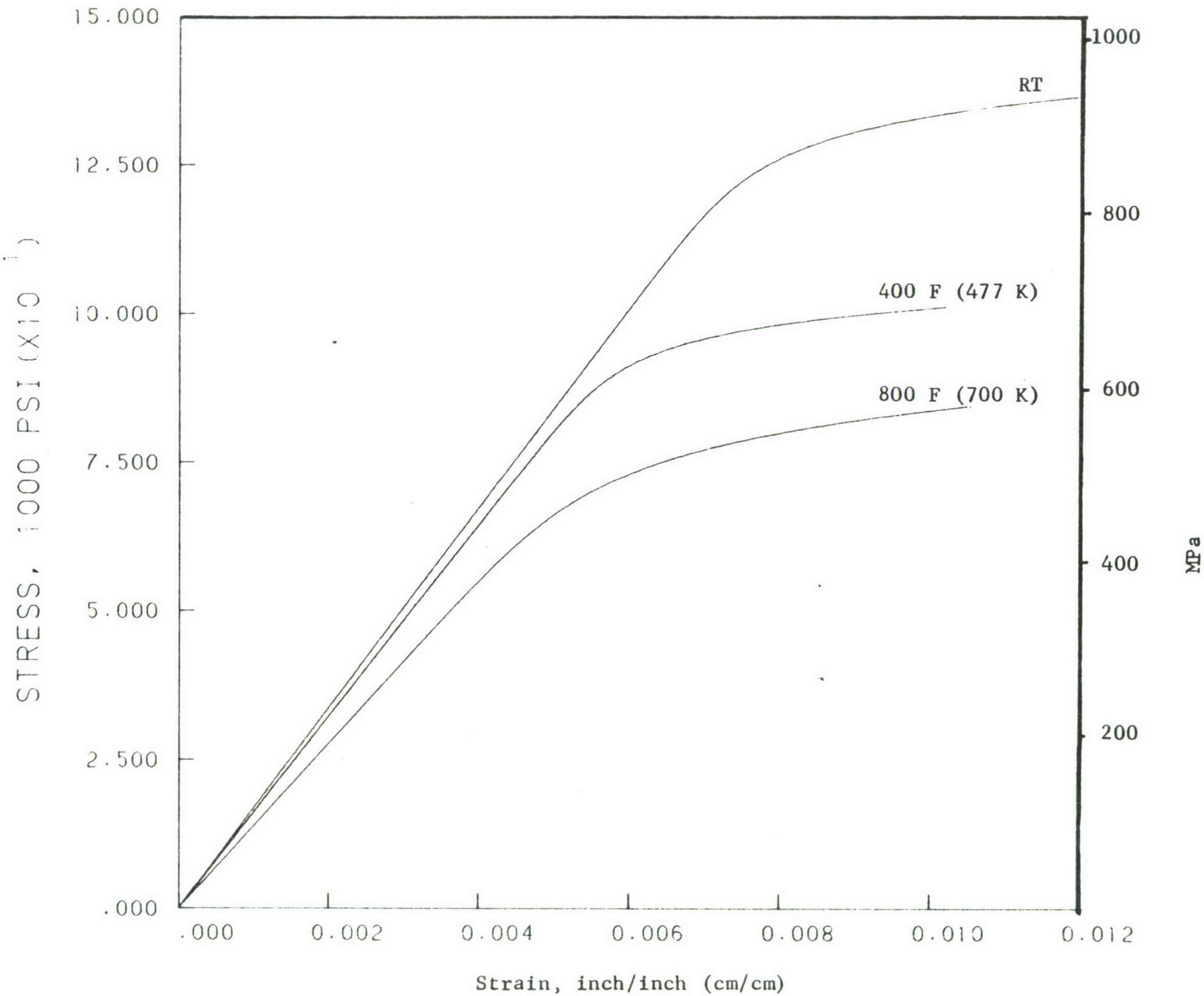

FIGURE 59. TYPICAL TENSILE STRESS-STRAIN CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (TRANSVERSE)

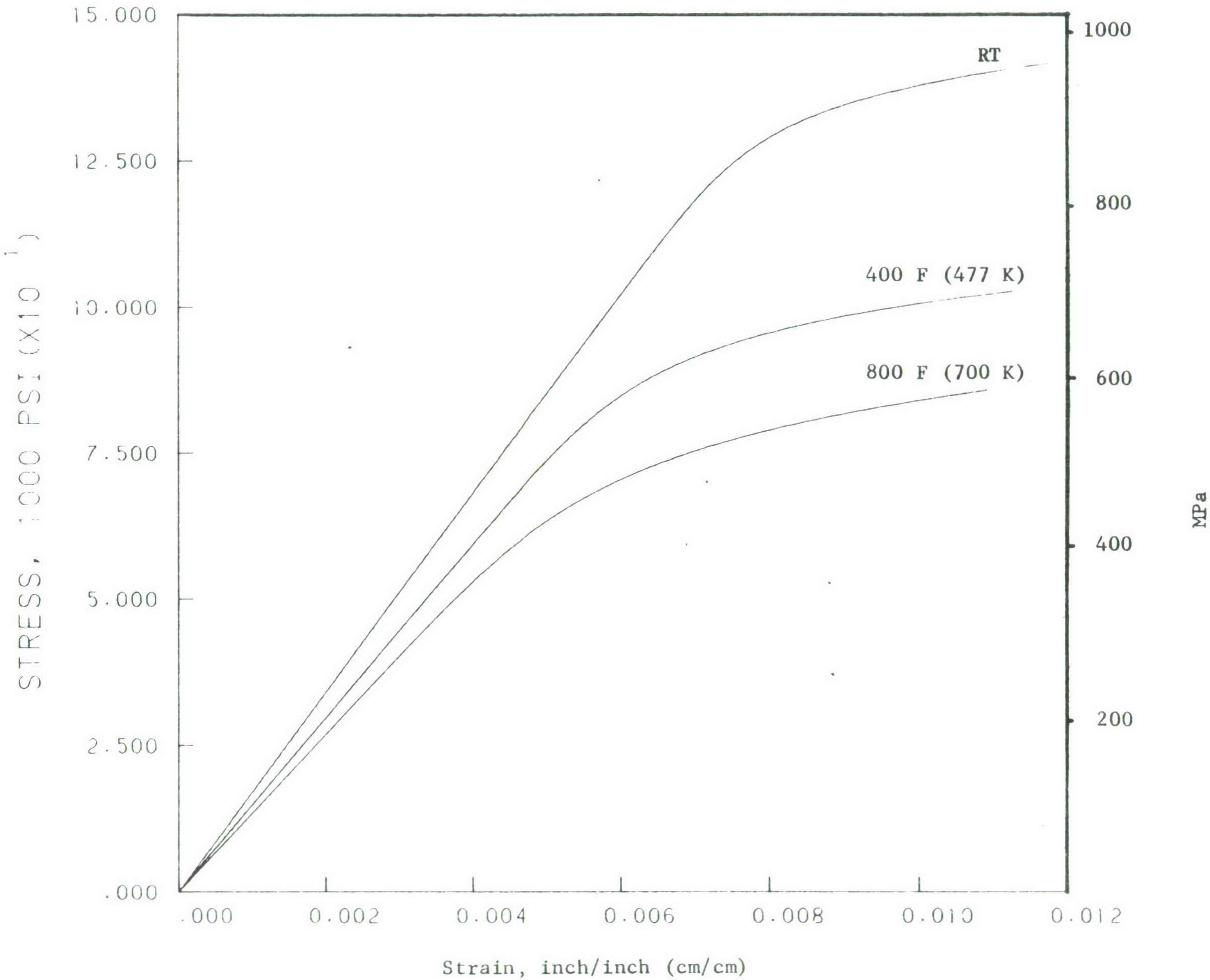

FIGURE 60. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (LONGITUDINAL)

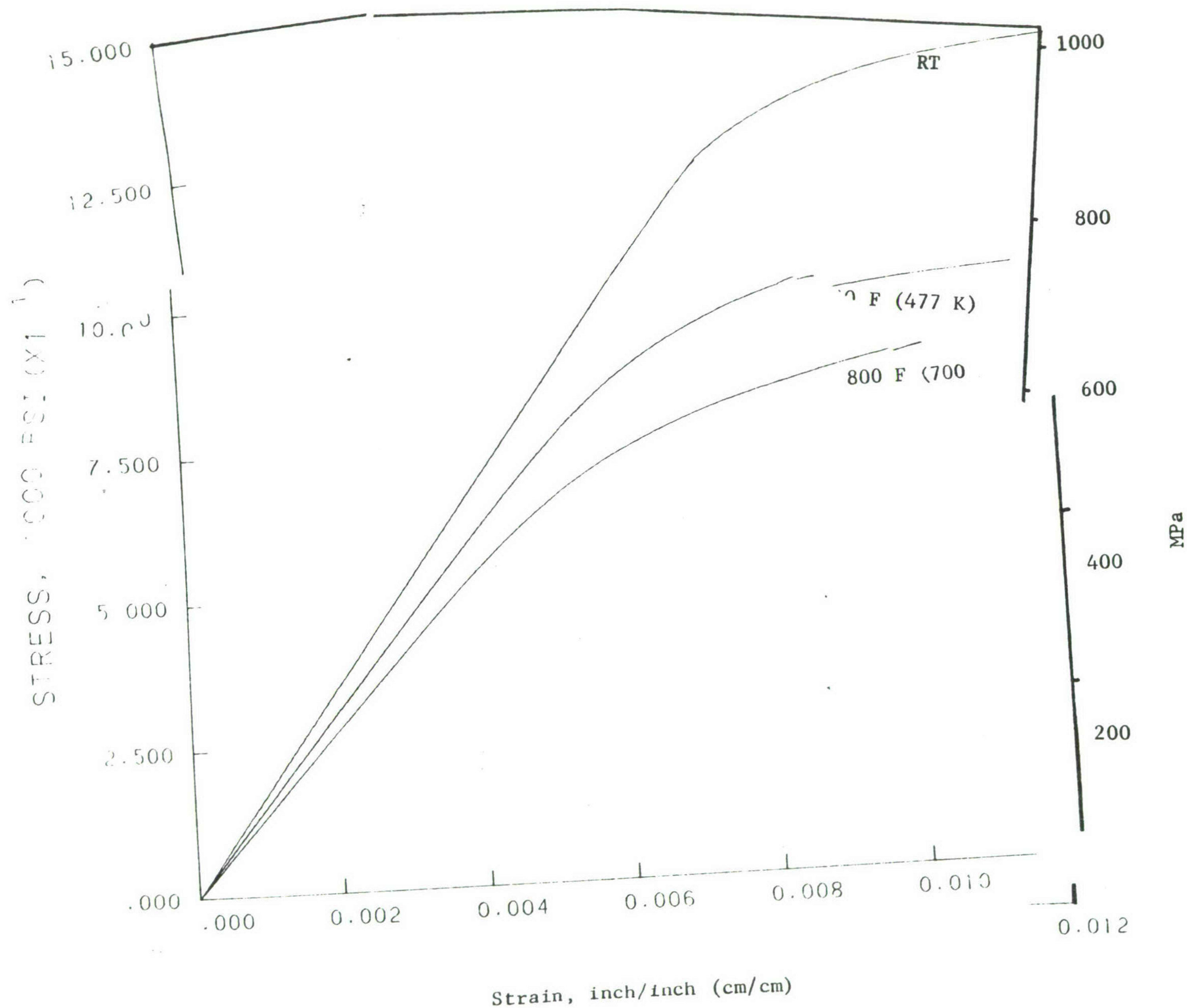

FIGURE 61. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (TRANSVERSE)

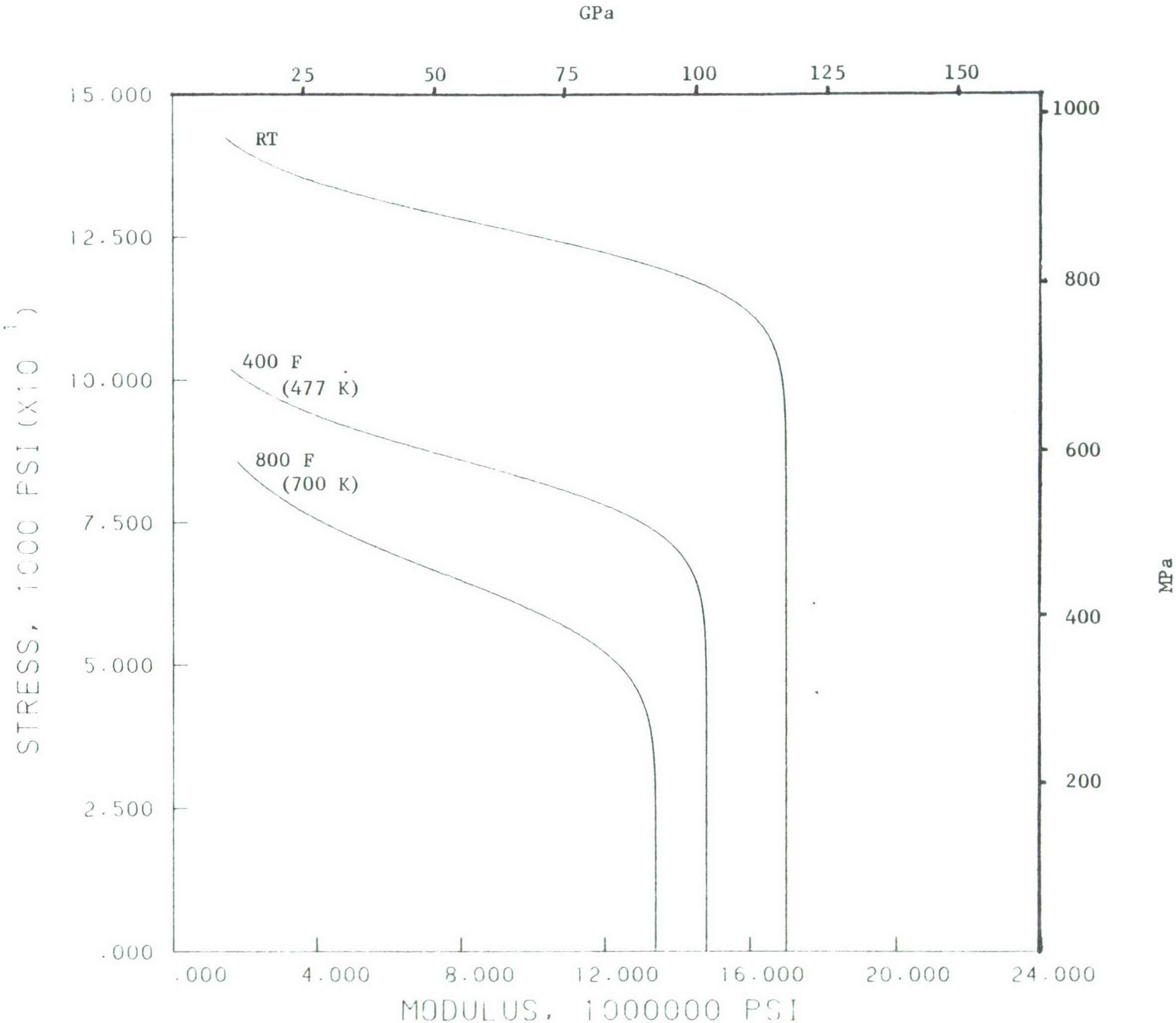

FIGURE 62. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (TRANSVERSE)

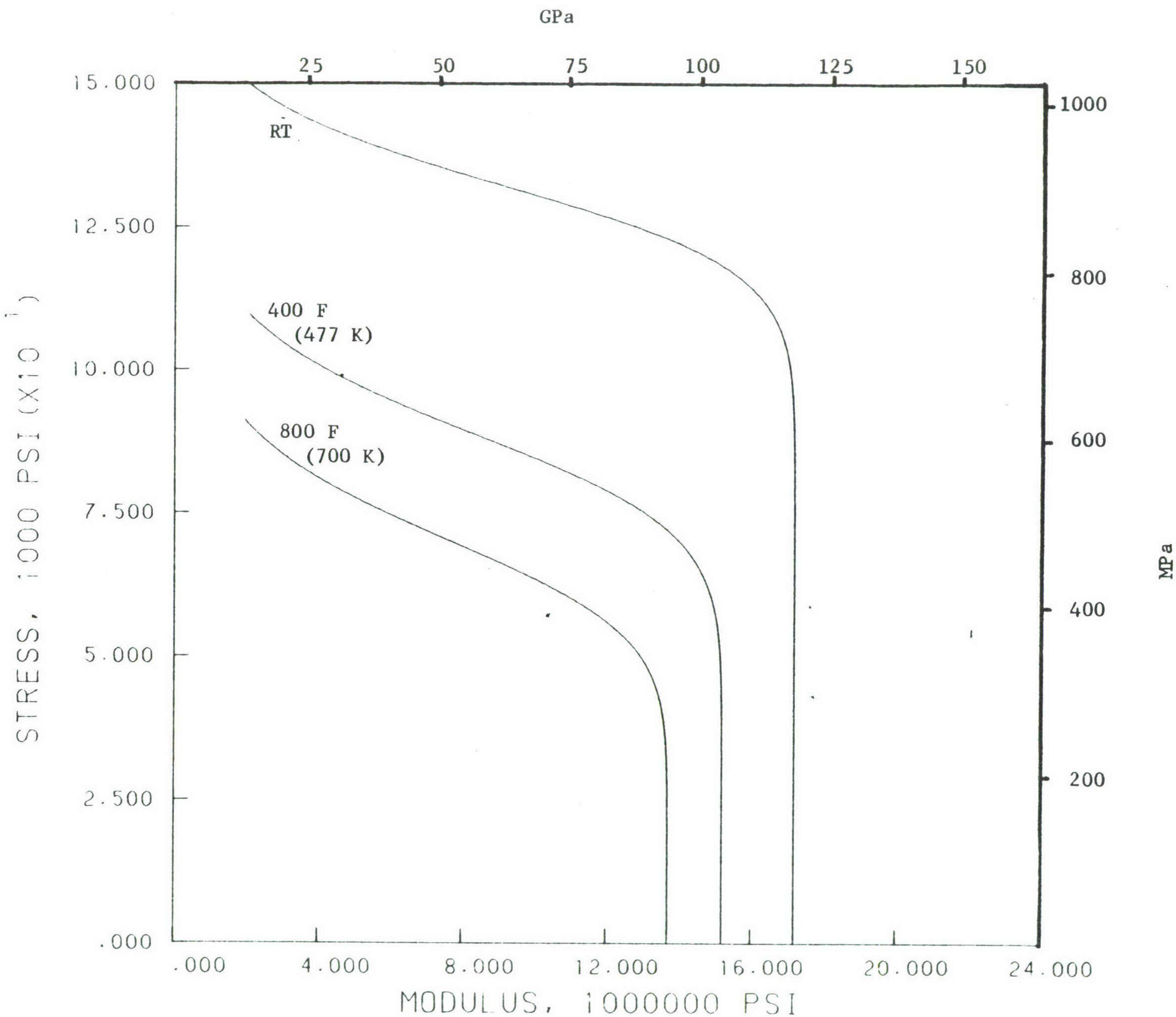

FIGURE 63. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY AT TEMPERATURE (TRANSVERSE)

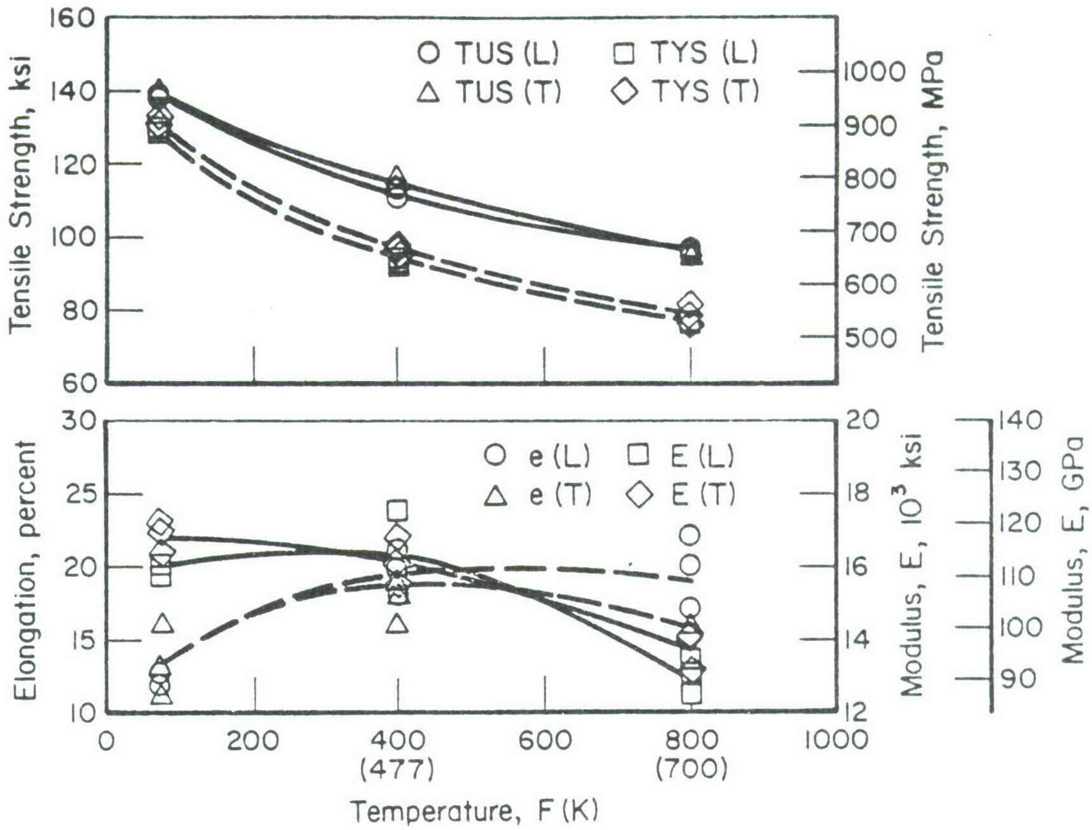

FIGURE 64. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA-PROCESSED CORONA 5 TITANIUM ALLOY

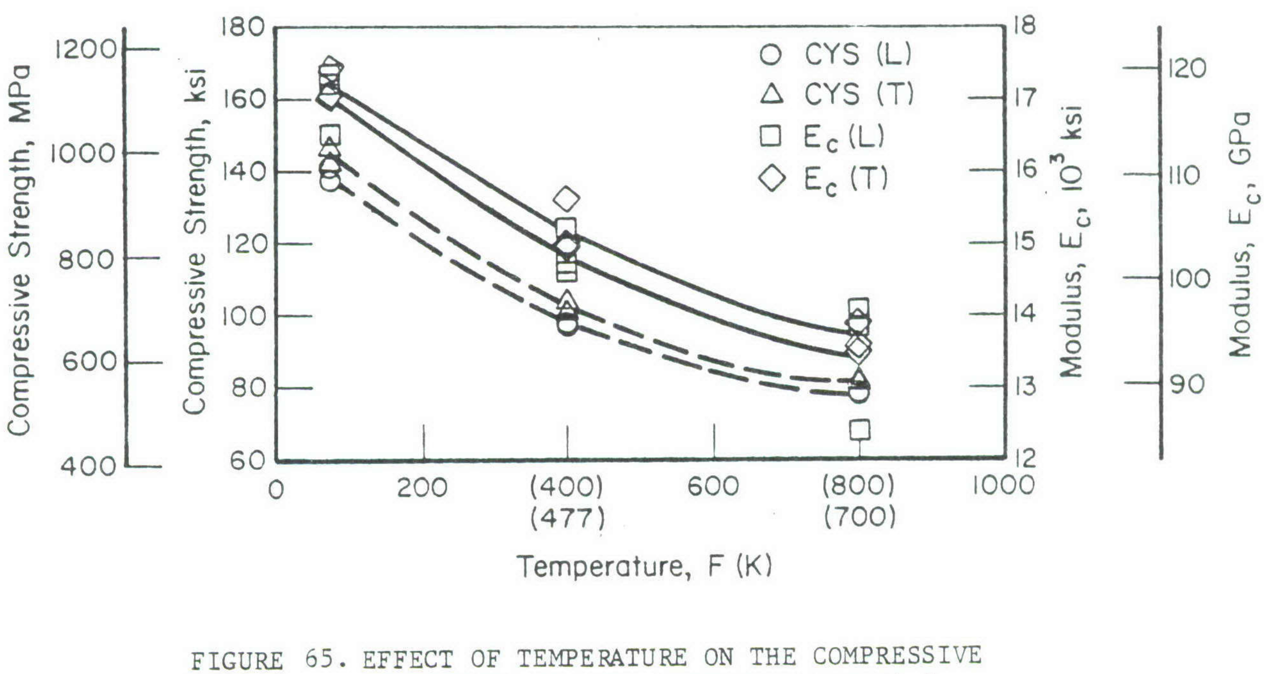

FIGURE 65. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF BETA-PROCESSED CORONA 5 TITANIUM ALLOY

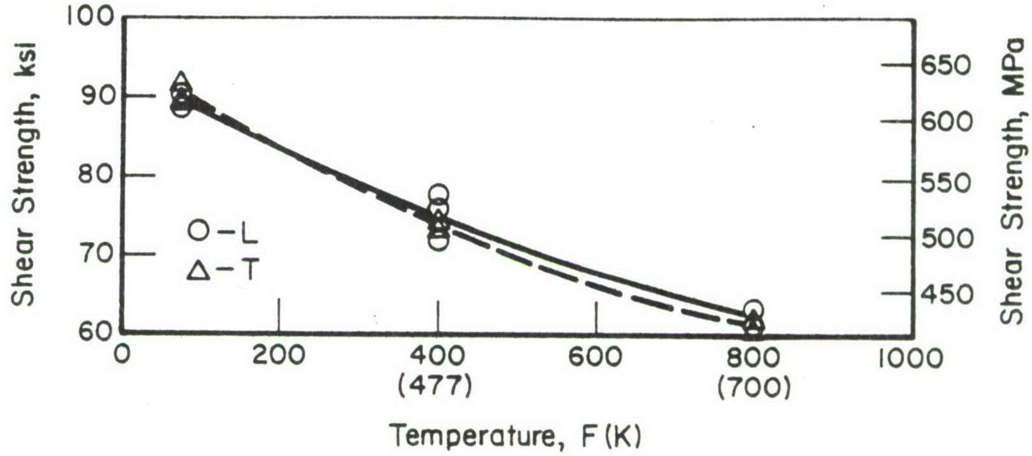

FIGURE 66. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF BETA-PROCESSED CORONA 5 TITANIUM ALLOY

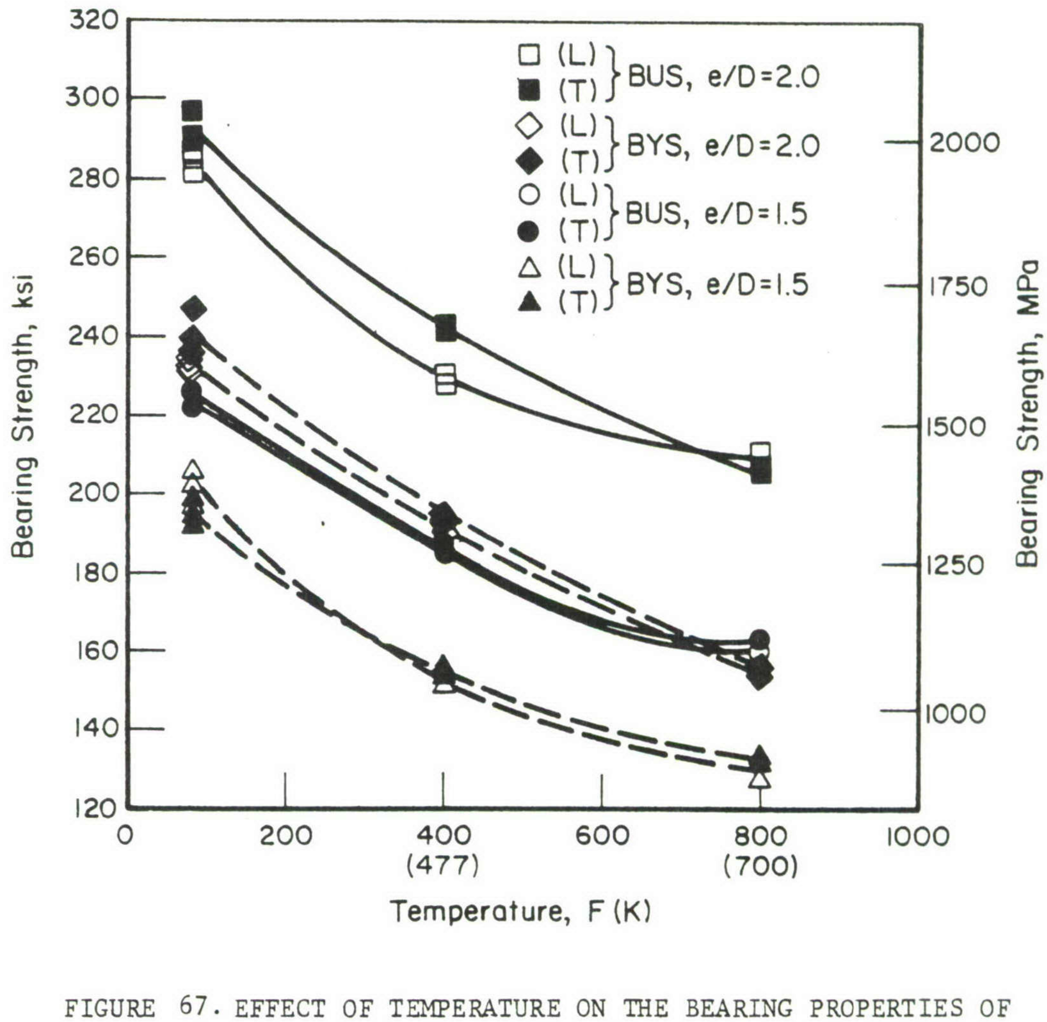

FIGURE 67. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF BETA-PROCESSED CORONA 5 TITANIUM ALLOY

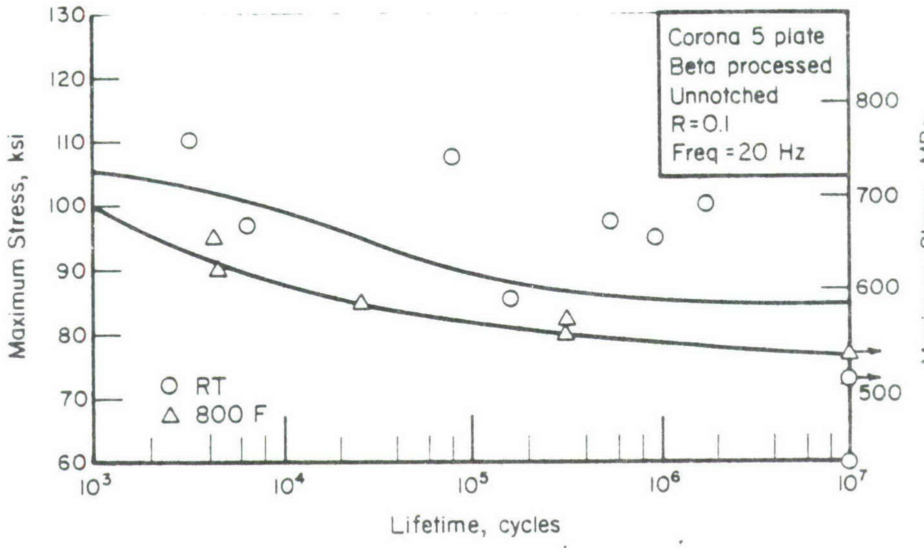

FIGURE 68. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED BETA-PROCESSED CORONA 5 TITANIUM ALLOY

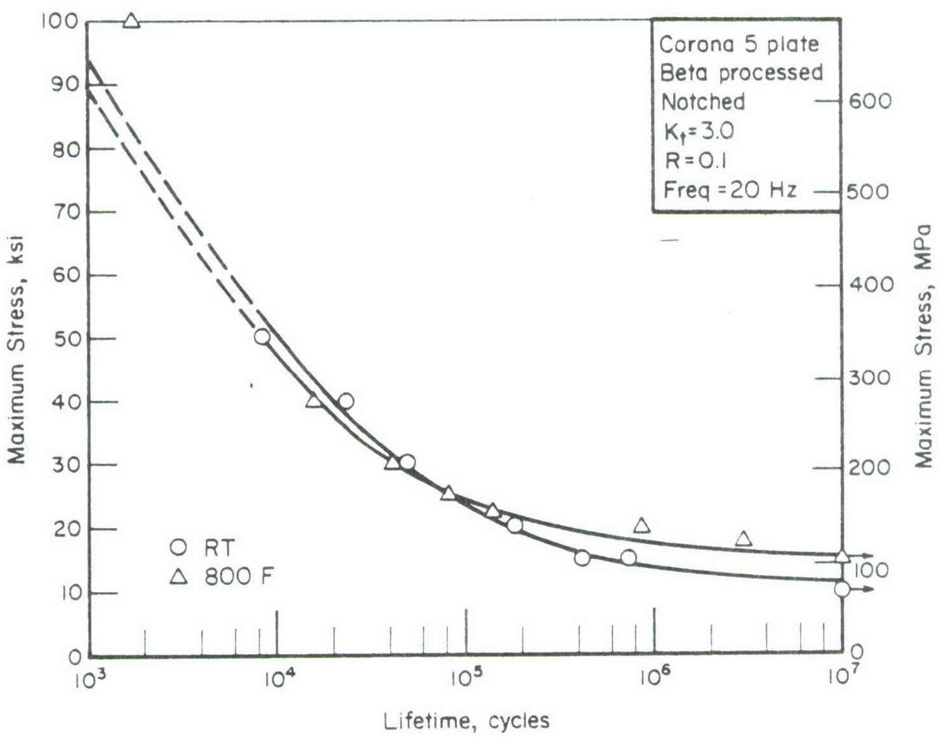

FIGURE 69. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) BETA-PROCESSED CORONA 5 TITANIUM ALLOY

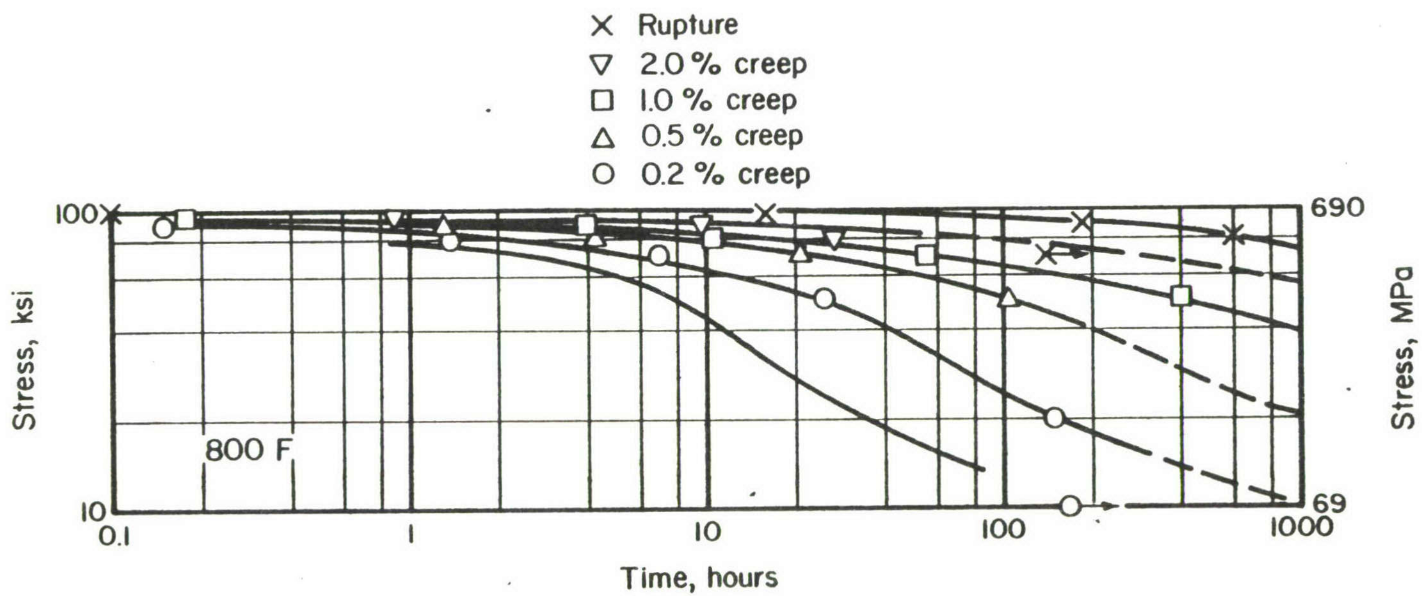

FIGURE 70. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR BETA-PROCESSED CORONA 5 TITANIUM ALLOY